Enumeration Strategy for Assessing Abundance of Coho Salmon within the Lower Fraser River Management Unit

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EXECUTIVE SUMMARY

Assessing escapement of Pacific salmon is a significant undertaking and has been a perennial challenge for fisheries managers throughout the Northwest. Limited and often uncertain funding, difficult access, and multiple populations of five species spread over hundreds of square kilometers and dozens of management units have been difficulties few organizations have been able to overcome sustainably. Further, changing governments with evolving policies and priorities coupled with numerous sampling designs and assessment methods available complicate the implementation of a long term, focused program for assessing salmon escapement and population trends.

The Lower Fraser Coho Salmon Management Unit (LFR MU) is comprised of the Lower Fraser, Boundary Bay and Lillooet Coho Salmon Conservation Units (CUs). While surveys of Coho Salmon escapement occur in the Lillooet and Lower Fraser CUs with some regularity, there is no focused assessment program or dedicated funding, and streams are primarily chosen for their pre-disposition to being assessed for Chum Salmon escapements. Assessing Coho Salmon escapement is, effectively, a matter of convenience and historically significant assessment programs within the Lower Fraser Management Unit (e.g. Salmon River) have been cancelled in recent years due to funding limitations and shifting priorities (e.g. more emphasis on Interior Fraser Coho). Further, there is no agreed upon method of estimating aggregate escapement to the entire LFR MU from the fraction of its component streams which are surveyed. Despite Canada’s commitments to the Wild Salmon Policy and the Pacific Salmon Treaty there have not been any recent aggregate escapement estimates to any of the three CUs or the MU which has made it challenging to effectively manage this population but also to assess management actions designed to enhance recovery.

The primary objective of this work was to evaluate alternative sampling designs and assessment methods for monitoring Coho Salmon escapement and population trends to the LFR MU. To support this evaluation, we collated all available escapement data since 1997 and reviewed a suite of sampling designs and assessment methods. To address these objectives, we developed a simulation-estimation procedure where we first simulated a time series of escapement data for Coho Salmon within the LFR MU. We then evaluated different sampling designs (random sampling of broodlines, random sampling of population units, index sampling of broodlines, and index sampling of population units) and assessment procedures (Area Under the Curve, Capture Mark Recapture, and Census) for their ability to estimate aggregate escapement to the LFR MU and to detect declining trends.

We found that an index sampling of population units coupled with AUC style assessment surveys performed best when estimating aggregate escapement. However, a random Population Unit design with AUC style surveys is preferred for monitoring population trends as aggregate patterns may be a poor reflection of overall population trends in a multi-population MU such as Lower Fraser Coho Salmon. Thus, managers may wish to implement two or more alternative but concurrent survey programs, depending on priorities.

INTRODUCTION

Coho Salmon abundance in Southern British Columbia has been declining since at least the mid-1980s (Peterman and Pyper, 2000) and it has been recognized that management of South Coast Coho Salmon needs to be conservative primarily to protect the co-migrating Interior Fraser Coho Salmon stocks (DFO 1998). This decline in abundance is due to numerous factors including over exploitation and climate driven declines in marine survival (DFO 1998; COSEWIC 2002), habitat degradation (Bradford and Irvine 2000), and changing marine conditions (Beamish et al. 1999). In the mid 1990's, DFO began managing Southern B.C. Coho Salmon fisheries to reduce exploitation rates from between 70% to 80% prior to 1993 to 60% (1996) and then to 25% to 35% (1997) (DFO 1998). Reduced exploitation rates have since been normalized and are currently estimated to be less than 10% (PSC 2013). However, reduced harvest rates have not resulted in increased abundance of South Coast Coho Salmon, as exhibited by both the continued need to maintain low exploitation rates, and the continued listing of Interior Fraser Coho Salmon despite its recent status downgrade to threatened (COSEWIC 2016) from endangered (COSEWIC 2002).

The Pacific Salmon Treaty (PST) (2014) designates Management Units (MUs) as the level to which fish and fisheries are to be managed. These are often aggregations of CUs. The Lower Fraser River Coho Management Unit (LFR MU), for example, is one of four Southern BC Coho Salmon MUs upon which fisheries assessment and management actions are to be delivered. The LFR MU includes the Lower Fraser, Lillooet and Boundary Bay Conservation Units (CUs), and is generally located between Pemberton, Hope, and the U.S.A/Canada border to Vancouver and includes the Pitt, Harrison, Chilliwack and Lillooet Lakes and watersheds (Figure 1). With three Lower Fraser CUs comprising the Lower Fraser MU, and the Pacific Salmon Treaty prescribing management actions at the MU level, the Lower Fraser CU, Boundary Bay CU and Lillooet CU are managed collectively by decisions made for the MU.

Assessment of Coho Salmon escapement to streams within the LFR MU is conducted by DFO, BC Hydro, the Douglas, Lil'wat, and Musqueam First Nations, the Fraser Regional Correctional Centre (FRCC) and the Stoney Creek Streamkeepers Association. In a typical year, DFO personnel conduct 75% of all stream surveys within the LFR MU and 90% of stream assessments within the LFR CU. However, each of the LFR CU sites surveyed by DFO has been selected with a priority for assessing Chum Salmon escapement, not Coho Salmon (L. Ritchie, pers. comm.). Further, of the streams assessed, only specific sites within, or portions of, each stream are surveyed. The Lil'wat and Douglas First Nations lead all stream surveys within the Lillooet CU. There currently are not, nor have there ever been, regular surveys to any stream within the Boundary Bay CU.

Salmon assessments in B.C. are conducted at one of three monitoring levels: indicator, intensive and extensive. Indicator programs are designed to assess abundance of adult populations (escapements) with a high degree of precision and low bias. Further, they are often affiliated with a coded wire tag program for juveniles which provides data on exploitation, harvest distribution and survival (Grant et al. 2007). Stringent operations and intense annual effort on these programs require significant funding. Within the LFR MU, the Salmon River

(Surrey, LFR CU) assessment program operated at the indicator level from 1993 – 2008 at which point DFO was no longer able to provide financial support. Thus, there is no indicator type stream within the entire LFR MU. The term "indicator stream" is also used when estimating escapement to a CU using the in-fill method (English et al. 2006 and English 2016), and is being applied by management to estimate escapement to salmon CUs on the North Coast of B.C. In this context, "indicator stream" refers to any stream which has regular, high quality escapement estimates, see English et al. 2006 and English, 2016 for further description. Intensive assessments refer to those study sites that generate consistent estimates of spawners between years and may use fence, mark-recapture or visual survey techniques to estimate escapement (Grant et al. 2007). Despite the advantages of a fence or mark recapture program, all intensive assessments in the LFR MU are via visual surveys which are less precise but also less costly. All surveys of Coho Salmon within the LFR MU are conducted using intensive assessments. Extensive assessments are of a qualitative nature and provide only relative estimates of abundance and distribution. Extensive assessments are not conducted within the LFR MU.

Noble et al. (2015) determined that the LFR MU escapement record was data deficient and unsuitable for stock-recruit and fisheries management purposes. These concerns were also noted by the PST Coho Technical Committee (PSC 2013) and have resulted in a designation of annual "low" or "NA" abundances. Reasons for this include general concerns with the quality of the escapement record, the lack of indicator streams in the Lillooet and Boundary Bay CUs, the loss of Salmon River as an indicator within the LFR CU and the general absence of data for the Boundary Bay CU. The lack of a consistent escapement estimate is a critical information gap for the bilateral management of Coho Salmon and has resulted in exploitation being capped at 20% (PST, 2014) since at least 2004 (PSC 2013), though it is often less. The lack of a dedicated survey program specifically designed to estimate Coho Salmon escapement to the LFR MU has limited the opportunity to confidently estimate escapement, design a rebuilding plan or adequately estimate the effects of management actions.

Assessment of salmon abundance is both technically challenging and financially onerous, and the chosen observational models are rarely unanimously supported by all interested agencies. Multiple options are available for assessing escapement to a stream and the option(s) selected require explicit trade-offs of several factors including costs and desired precision and bias, amongst others. Among the more commonly chosen observational models are peak count times two, area under the curve (AUC), mark recapture, and census (e.g., fishway or weir) type assessments. Most observational models are likely to generate escapement estimates that are negatively biased due to difficulty seeing Coho Salmon, but also surveyors sampling only a portion of streams (Irvine et al. 2001). Mark recapture studies on the Interior Fraser Coho MU found that surveys can miss significant numbers of Coho Salmon, but that the degree of bias is not uniform across all populations (Irvine et al. 2001).

Sampling design is a significant factor for management to consider when selecting an appropriate sampling protocol. Due to the inherent complexity in Pacific Salmon CUs, the large complexity in geography over which they are found, and natural differences in abundances, sampling design must be specific to a species, CU or region. The advantage of evaluating alternative sampling designs is that one can be selected that is most likely to provide the agency with the data it desires or the resources it has while making assumptions and trade-offs clear. For example, it is common in fisheries management to want to be able to assess the status (i.e. annual abundance, trends in abundance, distribution, etc.) of a population but these all require a different, and often rigorous, sampling design (Holt et al. 2011, Peacock and Holt, 2012). The Committee on the Status of Wildlife in Canada (COSEWIC), for example, uses the rate of decline over 10 years to establish whether a species should be listed as Endangered or Threatened (50% and 30% declines, respectively), while DFO is very interested in annual estimates of abundance. These different objectives might dictate very different sampling designs.

The state of Oregon has been actively designing and experimenting with sampling design since 1990 when a stratified random sampling (SRS) design was implemented to generate more accurate annual estimates of spawning escapement of Coho Salmon (Jacobs and Nickelson 1998). The SRS design selected survey sites at random from within an geographical unit (strata). However, this design was not spatially balanced and in 1998 Oregon implemented a rotating panel design (Generalized Random Tessellation Stratified Design (GRTS)) to provide a spatially balanced estimate while also permitting the integration of data from spawning surveys, juvenile studies and habitat work (Firman and Jacobs 2001, Stevens 2002, Sounhein et al. 2016). Rotating panel designs provide the best compromise between status estimation and trend detection; however, they tend to require a long term commitment (9 - 27 years) (Adams et al. 2011) and significant and dedicated funding. In fact, Oregon modified its GRTS design to reduce the length of panel rotations from 27 years to 9 years (Stevens 2002). GRTS is considered the best compromise between the need for randomization and the need for spatial balance (Adams et al. 2011). DFO does not currently have dedicated funding for assessing Coho Salmon escapement to the LFR MU which is required to implement any specific sampling design.

In the North and Central coasts of BC, DFO has implemented the English method for assessing escapement to a CU (English et al. 2006 and English 2016). This method is advantageous in that its assumptions are well known, and both historic and future data can be used - thus extending the time series available for analysis. It requires both the use of high quality escapement data (Type 3 or better) that is collected annually from specific streams (referred to as “indicators”) but also escapement data from streams surveyed less frequently or less regularly (referred to as “non-indicator”). This is advantageous as it provides flexibility to the manager as to which surveys are conducted when, so long as the indicator streams are assessed regularly and that, at some point, non-indicator streams do get assessed again. However, depending on streams selected to survey, the English method may not be spatially balanced, may not capture changes in distribution over time and assumes that the relative contribution to escapement between indicator and non-indicator streams remains relatively static.

In this work, we developed a simulation-estimation procedure to test escapement enumeration strategies for Coho Salmon within the LFR MU. Specifically, we simulated escapement using an exponential growth model with a stochastic time series in order to simulate escapement for a series of spawning sites within a region. We then tested different sampling designs and assessment methods that will generate estimates of escapement to each of the three component CUs, and thus to the MU. The sampling designs were tested in its ability to detect a 30% and 50% decline in abundance (escapement) over three generations (per COSEWIC), as well as its ability to estimate aggregate annual escapement to each CU and thus to the MU.

This project was completed through funding received from the Pacific Salmon Commission Southern Fund in 2016. The primary objective of this contract was to develop a sampling design for estimating aggregate Coho Salmon escapements within the Lower Fraser River Management Unit. The following tasks were undertaken to achieve the project objective:

1. Review and evaluate existing escapement records
2. Review of potential approaches
3. Develop Simulator of Lower Fraser Coho Salmon abundance
4. Develop criteria for evaluating alternative sampling designs
5. Evaluation of final suite of sampling designs for evaluation
6. Reporting

METHODS

A Monte Carlo simulation procedure was used to evaluate the efficacy of different sampling designs and assessment methods for estimating escapement and monitoring population trends within the LFR MU. Details on our methods for estimating empirically-based input parameter values are provided in Appendix A.

The primary objective of the simulation-estimation procedure was to consider the optimal selection of unique Population Units (PUs) for escapement assessment within the LFR MU (Figure 2). A Population Unit is equivalent to the POPID code provided in the New Salmon Escapement Database (NuSEDS) where each POPID refers to a unique salmon population within the LFR MU and as an aggregate comprises the MU (Figure 2). Due to lack of available information (watershed characteristics, river discharges and water levels, specific locations of spawning and holding water, etc.) as well as being outside the project scope, the study does not consider how best to execute surveys within each PU. Rather, the current study focuses on how best to execute surveys within the MU, regardless of potential differences between PUs or CUs.

DATA SELECTION

Escapement Estimates

DFO and its partners attempt to conduct annual surveys to streams to assess escapement abundance of Coho Salmon. Once surveys are complete and data is submitted, DFO scores the quality of escapement estimates from one through six where one is this “best” and six the “worst”. Typically, a score of three or less is preferred. We summarize the quality of escapement estimates from 1997 – 2015 for each CU in Table 1. Funding for surveys is inconsistent for both DFO and its partners, thus the number of days spent surveying streams is inconsistent over time. However, crew from all agencies can, on average, conduct almost two surveys (two streams) per day, thus the total number of surveys in most years is almost double the number of days of effort (Figure 3).

We used escapement data from 1997 – 2015 (Appendix B Escapement Data) to inform both the simulation model structure and to derive parameter values (Appendix A). Escapement data for PUs within the LFR MU from 2004 - 2015 were provided by DFO (Lynda Ritchie). This data, specifically, had undergone internal review by DFO and thus differs from that provided in NuSEDS. Despite this data being released for this project, it has not yet undergone final review for broad release, thus the data in NuSEDS has not been updated to reflect the data (post 2004) used in this project. This dataset (hereafter referred to as the DFO dataset) includes data provided by the Lil'wat and Douglas First Nations, the Salmon Enhancement Program (SEP) and DFO stream surveys.

In order to better simulate broodline escapement data and assess the broodline sampling design the time series of escapement was extended to 1997 with escapement data exported directly from NuSEDS for years 1997 – 2015. Where escapement estimates existed for the same stream/year combination in both the NuSEDS export and the DFO dataset, the data in the DFO dataset was selected with the exception of Salmon River, which was considered to be more accurate in the NuSEDS database (Lynda Ritchie, pers. comm). This final dataset used for the simulation-estimation procedure is referred to as the "empirical dataset". The year 1997 was selected as our initial year primarily to support broodline analysis as 1997 – 2015 provides escapement data for two full cycles of each broodline. Once data was compiled, there were a total of 7 (Boundary Bay), 471 (Lower Fraser) and 121 (Lillooet) escapement values available for parameterizing the simulator (Table 1). Within the LFR MU, there are a total of 143 PUs identified as bearing Coho Salmon, with Boundary Bay having 4; Lower Fraser River having 117; and Lillooet having 22. Final escapement values used to develop the simulator are provided in Appendix B Escapement Data.

Significant effort was expended to supplement the DFO dataset and NuSEDS data with data from other sources that may not be part of the official record. First Nations were the focus of this effort, but also agencies like (BC Hydro, Alouette River Management Society), non-profits and municipalities were contacted (Table 2).

Survey Effort

We used the significant meta-data (Appendix B Escapement Data) from the DFO dataset to generate the total effort (number of days) all agencies deployed for assessment surveys. To do this we sorted dates where a survey was conducted, by each agency, and selected for unique values, thus producing the total number of days each agency conducted stream assessments. Further to this, we estimated the number of inspections each agency conducted each day by dividing the total number of stream inspections by the total number of days of effort. When assessing sampling designs, survey effort was used as a proxy for cost, as the largest expense with most ground-based salmon assessments is personnel costs.

DESIGN CONSIDERATIONS

Potential sampling designs and assessment methods were determined during a collaborative meeting held on December 2, 2016 with DFO (Richard Bailey and Lynda Ritchie) and LGL (Cameron Noble, Wendell Challenger and Bob Bocking). During this meeting four sampling designs were discussed: rotating panels, Index site selection, random site selection and a generalized random tessellation stratified (GRTS). Five assessment methods were also discussed for inclusion, each with specific metrics such as coefficient of variations (CVs) (precision) and total minimum person days (effort) required to complete each type of assessment method (

Table 3). After this meeting, it was decided that we would evaluate both an index and random sampling design, each of which would be tested on monitoring PUs and broodlines, and each of these four combinations (Figure 4) would be tested with area-under-the curve, capture-mark-recapture, and census type assessment methods. With the exception of census style assessments, for which low effort scenarios did not necessarily provide enough effort, each assessment method was evaluated using all combinations of precision (low medium and high) and effort (low, medium and high). In total we evaluated 80 combinations of sampling design,, assessment method, precision and effort (

Table 3) for each CU and the MU.

SIMULATION MODEL

The primary goal of the simulation model was to generate an abundance time series for each PU in the LFR MU with properties that were similar to those observed in the empirical dataset. Because the smallest spatial unit available associated with escapement data was the NuSEDS POPID (PU) the aim of the simulator was to produce yearly escapement abundances for 143 unique PUs amongst the three CUs. The simulator was also designed such that the simulated escapements would mimic spatial and temporal patterns observed in the historical dataset (Appendix B Escapement Data).

Yearly escapement abundances for each PU were simulated with assessment error; where assessment errors were specific to each of the three assessment methods tested (area under the curve [AUC], capture-mark-recapture [CMR] and census [CEN]) and the precision scenario used for that method (low, medium and high) (Table 3).

Each assessment method was assumed to have a different implementation cost (person days), which dictated the total number of PUs that could be surveyed in each estimation iteration under fixed effort scenarios (Table 4). Where applicable, different effort scenarios (i.e., low, medium, and high) were considered for each assessment method. Finally, sampling designs considered how and when to select PUs for assessment, with total effort allocated proportionate to the number of PUs within each of the three CUs under study.

One of the objectives of the study was to look at the trade-off between effort and precision for the different assessment methods and the overall ability to estimate trends and the ability to derive estimates of total escapement. We also consider how the total sampling effort could potentially be allocated towards different management objectives (e.g., escapement estimates versus trend estimation) as well as how effort may be best distributed regionally across the three conservation units (i.e., BB, LFR and LILL).

Simulated Escapement Time Series

Escapement time series were generated using an approach similar to Holt et al 2011, which was designed to simulate the “spatial and temporal variation in salmon abundance at multiple sites within a region”. The basic approach combines an exponential growth model with a stochastic time series to simulate escapement for a series of spawning sites within a region (e.g., PUs within a CU). The stochastic time series is used to generate a stable time series of PU-specific abundances, which is then re-trended based on an exponential growth model and PU-specific trends drawn from a distribution of trends that reflect the average trend within the region. The empirical dataset used to parameterize the simulator also did not show signs of complex multi-year cyclic behaviour as observed in some Pacific salmon species. Our approach therefore focuses on replicating and measuring an average of the individual PU trends (e.g., average PU trend), where complex multi-year cyclic behaviours are not present.

During initial analysis of empirical escapement data, evidence was found for consistent 3-year cycles within the DFO dataset (Figure 5 and Figure 6). These observations include a difference in the average PU escapements that occurred every three years within the two CUs that had consistent repeatable observations (LFR and LILL; Figure 5). The 3-year pattern was also observable within nearly all PUs (Figure 6). While the exact mechanism is not known, we hypothesize that it may arise through a combination of a strict 3-year life-cycle, and spawning site fidelity. If true, this implies the 3-year patterning may be the result of three independent parental lines driving yearly spawning abundances observed at each PU. Within this study we refer to this hypothesized mechanism as the “broodline” effect.

The concept of broodline effects for Lower Fraser Coho is similar to the concept of “cycle lines” in Fraser River Sockeye, except within this study we are using broodline to refer to the cyclic patterning observed in the average PU escapement rather than cyclic patterns observed in the aggregate return. This distinction is important as we adapt the approach of Holt et al. 2011 for the current study objectives. Furthermore, the exact mechanism behind the cycle lines phenomenon of Fraser River Sockeye is still up for debate with multiple competing hypotheses. For these reasons we have opted to use a different term to describe similar phenomenon observed in Lower Fraser Coho. Within the context of this study we have labeled the broodlines A (1997, 2000, 2003, …), B (1998, 2001, 2004, …), and C (1999, 2002, 2005, …) for convenience. Appendix C Ancillary Analyses contains more details on these findings.

The basic approach of Holt et al. 2011 was extended to incorporate the differences in broodlines that are hypothesized to occur within each PU. The approach of Holt et al. 2011 was also further refined for our study by allowing trends to be targeted at different scales, from the PU to the aggregate trend observed at different management scales (i.e., CU and/or MU). Here we define aggregate trends as the trend observed in aggregate totals of abundance that can occur when yearly abundances at each PU are combined (e.g., for the CU or MU total). Trends based on aggregate totals more closely follow the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) quantitative and critical guidelines to guide the status assessment of wildlife species. We also consider monitoring the average PU trend as a potential alternative for monitoring population health. Observations were generated from the simulated data based on the combination of the sampling design (i.e., how PUs were selected from the larger pool) and assessment methods under considerations (i.e., precision and effort).

Care and attention was taken to ensure that the patterns exhibited by the simulator closely matched observed patterns (Figure 7); however, it was not possible to include all population attributes. While Lower Fraser Coho Salmon do exhibit spawning site fidelity it will not be to the degree that each PU acts in a completely independent fashion within each CU. While these types of spatial associations were tested for during the exploration phase of the study, no reliable structuring could be determined. In this situation, an assumption of complete independence was the only workable solution. That said, while this assumption may not be perfectly valid, validation testing of the simulation model did produce patterns at the local and aggregate level that were nearly indistinguishable from the empirical data (Appendix D Validation Analyses).

MEASURING TRENDS

Under the COSEWIC guidelines for "decline in total number of mature individuals" a status of threatened or endangered can be set based on population declines of 30% or larger and 50% or larger over the last 10 years or 3 generations, whichever is longer (COSEWIC 2017). Under this criterion Lower Fraser Coho may be designated as threatened if a decline of 30% or larger occurs within 10 years. Depending on whether the decline is reversible, source of the decline is known, and the cause of the decline has ceased the criterion of 50% or larger and 70% or larger may also be used.

Simply comparing two endpoints over the last 10 years for a specific level of decline would provide an estimate with a large amount of uncertainty. An alternative approach is to use all years of data to measure a rate of decline that matches or exceeds the COSEWIC criterion. An exponential growth model provides a straight-forward way to accomplish this task. The general form of the exponential growth model is (all parameter values can be found in (Appendix A Parameter Values):

$$S_t = S_0 e^{r \cdot t} \qquad \text{Equation 1}$$

where S_t represents the total number of spawners in the population time t, S_0 represents the spawner abundance prior to the start of the monitoring period and r represents the population growth rate. Both S_0 and S_t represent the aggregate total of abundances summed across applicable PUs. Working with log abundances allows r to be estimated using standard approaches such as linear regression:

$$\log(S_t) = \log(S_0) + r \cdot t. \qquad \text{Equation 2}$$

Where the slope parameter is an estimate value of r, the value of which can then be compared against the expected value of r under the different COSEWIC decline criterion, were d represents the reduction in the spawner abundance over 10 years:

$$r = \frac{\log(1-d)}{9} \qquad \text{Equation 3}$$

In addition to estimating the trend in the total spawner abundance, we may also estimate the unique trends in a number PUs and use the average as an estimate of the larger regional trend. Here each PU j can be expected to exhibit a unique PU trajectory (r_j), and yearly abundances can be viewed as a composite of the three separate broodlines, each of which is specific to a given PU:

$$\begin{aligned} S_{t,j}^{A} &= S_{0,j}^{A} e^{r_j \cdot t} \quad \text{for } t = 1,4,7,\ldots \\ S_{t,j}^{B} &= S_{0,j}^{B} e^{r_j \cdot t} \quad \text{for } t = 2,5,8,\ldots \\ S_{t,j}^{C} &= S_{0,j}^{C} e^{r_j \cdot t} \quad \text{for } t = 3,6,9,\ldots \end{aligned} \qquad \text{Equation 4}$$

Here $S_{t,j}^{A}$, $S_{t,j}^{B}$, and $S_{t,j}^{C}$ represent the spawner abundances for broodlines A, B, and C in their respective years. The initial spawner abundances are represented by $S_{0,j}^{A}$, $S_{0,j}^{B}$, and $S_{0,j}^{C}$ respectively and they are assumed to share the same PU trend r_j. This series of equations can be represented by a single equation using B_t as an index of the broodline expected in year t:

$$S_{t,j}^{B_t} = S_{0,j}^{B_t} e^{r_j \cdot t}. \qquad \text{Equation 5}$$

To ensure compatibility with Equation 1 the site-specific growth rate r_j is defined as occurring on a yearly time scale which allows the time parameter t to indicate study year rather than broodline generation. The PU trend experience between generations within each PU broodline will be $3 \times r_j$.

The presence of a unique trend for each PU implies that an alternative method for monitoring population trends is to use average PU trend (i.e., $\bar{r} = \sum_j r_j / J$, where J is the total number of PUs sampled), which can be viewed as an estimate for μ_r the average PU trend within a given region (e.g., a specific CU and/or MU).

While we can expect the trend in the aggregate total (r) to be similar to the average PU trend ($\bar{r}$) the two are not equivalent. The average PU trend weights the contribution of each site equally, regardless of underlying spawner abundance, while the trend in the aggregate total effectively weights each site by the contribution to the total spawner abundance. Therefore, we can expect the latter to be more heavily influenced by the contributions of PUs with higher productivity.

Stochastic Time Series

Stochastic variation in spawning abundance was simulated as a stable time series of log abundances for each PU. Each PU time series was then re-trended to match a target trend in the aggregate total or a target average PU trend.

Simulating a Stable Escapement Time Series

A stable log abundance time series for each PU, $X_{t,j}$, was generated within each CU of interest (i.e., BB, LFR, LILL), based on linear combination of components representing the average log PU abundance, $\bar{x}_j$, the PU-specific brood effect, $\eta_{B_{t,j}}$, and random errors representing year-to-year discrepancies affecting all sites within a region, ω_t, and a residual error, $\epsilon_{t,j}$, that occurs independently for each site on each year:

$$X_{t,j} = \bar{x}_j + \eta_{B_t,j} + \omega_t + \epsilon_{t,j}. \qquad \text{Equation 6}$$

The average difference in the log abundances between each broodline within a PU is represented through the combination of the average PU log abundance, $\bar{x}_j$, and the PU-specific brood effect, $\eta_{B_{t,j}}$. Where possible estimates of average PU-specific log abundance $\left(\bar{x}_j\right)$ were directly used in the simulator (see Appendix A Parameter Values), otherwise values were drawn based on the following model:

$$\bar{x}_j = \mu_{\bar{x},j} + \gamma_j \qquad \text{Equation 7}$$

where $\mu_{\bar{x},j}$ represents the average regional log escapement (i.e. $\mu_{\bar{x},j} = \mu_{R_j}$, the average log escapement for a given CU) and γ_j is an error term representing site-to-site variability within a region, which represents a normally distributed random $\left(\text{i.e.}, \gamma_j \sim N(0, \sigma_{\bar{x}}^2)\right)$.

The brood-specific effect $\eta_{B_t,j}$ accounts for broodline-to-broodline differences at a given PU (j), with the index $B_t = \{A, B, C\}$ represents the broodline that escapes on a given year. The brood-specific effect is akin to a random effect, as the average effect across the three broods within a given site is restricted to sum to zero $\left(\text{i.e.}, \sum_{B_t=\{A,B,C\}} \eta_{B_t,j} = 0\right)$, but the individual $\eta_{B_t,j}$ values represent differences broods relative to the average site productivity (e.g., Figure 6b).

During the ancillary investigation of the DFO dataset (see Appendix B Escapement Data) it was found that estimated within-site brood-specific effects showed correlations both with average-local-population log abundance, $\bar{x}_j$ and other broodline effects within a given PU. Therefore, the $\eta_{B_t,j}$ values were generated in a step-wise procedure:

$$\begin{aligned} \eta_{A,j} &= \beta_{A,0} + \beta_{A,1} \cdot \bar{x}_j + \zeta_{A,j} \\ \eta_{B,j} &= \beta_{B,0} + \beta_{B,1} \cdot \eta_{A,j} + \beta_{B,2} \cdot \left(\eta_{A,j} \cdot \bar{x}_j\right) + \zeta_{B,j} \\ \eta_{C,j} &= \beta_{C,0} + \beta_{C,1} \cdot \eta_{A,j} + \beta_{C,2} \cdot \left(\eta_{A,j} \cdot \bar{x}_j\right) + \zeta_{C,j} \end{aligned} \qquad \text{Equation 8}$$

In the first step, the broodline A effect $\left(\eta_{A,j}\right)$ is generated as a linear combination of an overall regional average for broodline A ($\beta_{A,0}$), a proportion of the average log local-population abundance $\left(\beta_{A,1} \cdot \bar{x}_j\right)$, and a random error ($\zeta_{A,j}$). The broodline B effect $\eta_{B,j}$ was then generated as a linear combination of the regional average for Broodline B ($\beta_{B,0}$), a portion of the first realized broodline effect $\left(\eta_{A,j}\right)$, the interaction between average site-specific abundance $\left(\eta_{A,j} \cdot \bar{x}_j\right)$, and a random error ($\zeta_{B,j}$). The third broodline effect $\left(\eta_{C,j}\right)$ is then generated in the last step in manner similar to the second broodline except with different parameter values and separate error term. All random error terms were assumed to come from the same normal distribution $\left(\text{i.e., } \zeta_{B_t,j} \sim N\left(0, \sigma_\eta^2\right) \text{ for } B_t = \{A, B, C\}\right)$. Finally, because the individual $\eta_{B_{t,j}}$ values within a site are constrained to sum to zero $\left(\text{i.e., } \sum_{B_t} \eta_{B_t,j} = 0 \ \forall \ j\right)$, the individual brood-specific values for a given site were re-centered to ensure this constraint was upheld.

The regional ω_t yearly error represents general environmental stochasticity that may affect all spawning sites within a region on a given year. Often these types patterns can follow an autoregressive process this type of error can often follow an autocorrelation process. Based on the results from a formal model selection analysis on the DFO dataset (Appendix B Escapement Data) we used a first order moving-average ($MA(1)$) process:

$$\omega_t = \begin{cases} \tau_1 & t = 1 \\ \theta_1 \cdot \tau_{t-1} + \tau_t & t > 1 \end{cases} \quad \text{where } \ \tau_t \sim N(0, \sigma_\omega^2) \qquad \text{Equation 9}$$

where $\theta_1$is the lag-1 coefficient and τ_t is a normally distributed random variable.

Finally, $\epsilon_{t,j}$ represents residual error unique to the abundances exhibited by each PU on each year was modeled as being normally distributed $\left(\text{i.e., } \epsilon_{t,j} \sim N(0, \sigma_\epsilon^2)\right)$. While the model selection analysis also showed evidence for moving-average process on the residual errors, a simulator that only included a moving-average process on the ω_t error term exhibited similar behaviours.

Adding Time Trends

A linear trend was applied separately to the log abundance time series of each PU separately, where each PU was assigned a unique trend from a distribution of population trends. This created a set of abundance time series where the average PU trend matched a target trend. Because the average PU trend can differ from the trend exhibited by the aggregate totals, an adjusted factor was determined whereby each PU trend could be further adjusted until the trend exhibited by the aggregate totals matched the targeted trend.

Applying the PU trends

All the broodlines within each PU was assumed follow a unique population trend $\left(r_j\right)$ which was from a normal distribution with a mean regional trend of μ_r and a variance of σ_r, that is,

$$r_j \sim N(\mu_r, \sigma_r^2). \qquad \text{Equation 10}$$

The parameter μ_r represents the average PU trend across all PUs within a region under study (e.g., individual CUs or the MU) and σ_r represents the site-to-site variability within the region. While the average trend across all sites within a CU can be expected to be μ_r, the low number of sites for some CUs (e.g., Boundary Bay) implies that the realized average on any given simulation could deviate substantially from μ_r (Figure 8). To remedy this all random draws of site-specific trends, were re-centered within each region (i.e., $\sum r_j = \mu_r$ for all j within a CU).

This trend was then applied to the stable abundance time series of each PUs' broodline. Briefly, the realized trend in the stable time series was estimated by regressing the timer series log abundance $\left(X_{t,j}\right)$ time t. Using the broodline specific exponential growth equation (Equation 5), separate log abundance regressions were fit for each PU broodline:

$$\log\left(S_{t,j}^{B_t}\right) = \log\left(S_{0,j}^{B_t}\right) + r_j^{B_t} \cdot t \quad \text{for } B_t \in \{A, B, C\} \qquad \text{Equation 11}$$

Here the slope parameter estimate from the regression is an estimate of $r_j^{B_t}$. While the average trend for the stable time series will be zero on average, due to the stochastic nature of the stable time series, the estimated PU-specific rate can be expected to differ from zero on any given simulation realization. Residuals from each broodline regression were then saved and combined with predictions made based on the regression parameter estimates and the unique trend assigned to each PU. Because of the intergenerational time-period a slope of $3 \times r_j$ was used in predictions, where the r_j were randomly drawn based on target trend of interest (i.e., u_r in Equation 10). This produces the final trended log abundance time series values $X_{t,j}^T$ for each PU broodline. The process was repeated for all PUs across all simulation iterations.

Exponentiation of the trended log abundance time series gives the actual site-specific abundance $\left(\text{i.e., } S_{t,j}^{B_t} = \exp\left(X_{t,j}^T\right)\right)$. Because the r_j's for a given region of interest (i.e., an individual CU or MU) were centered the average broodline trend averaged across all PUs within that region exactly matched the target trend.

The value of μ_r is then set depending on population decline of interest. For example, a 30% decline over 10 years will be approximately -0.040 (i.e., $\mu_r = \log(1 - 0.3)/9$). The corresponding trend broodline generation would be approximately-0.119.

Creating the aggregate trend

While the average PU trend will match the target, the trend in the aggregate abundance totals may not. As such, an optimizer was used to determine a multiplicative factor by which each PU trend (r_j) can be multiplied by to ensure the aggregate abundance matches the target trend. This conversion factor was then used to re-trend the original stable time series as described in the previous sections. Aggregate trends were enforced at both the CU and MU level. Because each CU is given the same aggregate trend, the MU will also exhibit the same trend.

The simulation study considered true population trends from 10% to 90% decline over 10 years at both the PU and aggregate level. For simulation runs considering time horizons greater than 10 years (e.g., 20 years), the same rate of decline was used across all simulated years.

Sampling

While true number of spawners at each PU on each year is known in the simulation, it is not known in reality. Instead, these values must be estimated based on an assessment method applied to each PU, which is assumed to have a set of possible precisions. As such, the observed number of spawners $S_{t,j}^{\mathrm{OBS}}$ at a given PU in a given year is a product of the true number of spawners $S_{t,j}$ and the observation-error term $\nu_{t,j}$, that is:

$$S_{t,j}^{\mathrm{OBS}} = S_{t,j} \cdot \exp\left(\nu_{t,j}\right). \qquad \text{Equation 12}$$

Here $\nu_{t,j}$ is a normally distributed random variable with a mean of zero and a variance of σ_v^2 $\left(\text{i.e., } \nu_{t,j} \sim N(0, \sigma_v^2)\right)$. The exact years ($t$) and sites ($j$) selected in the $S_{t,j}^{\mathrm{OBS}}$ data set depends on the assessment method, total effort and sampling design under consideration.

We consider three possible types of assessment methods (i.e., census [CEN], capture-mark-recapture [CMR], and area under the curve [AUC]) each possessing a different precision, which we summarize as the coefficient of variation (Table 3). These values were agreed upon through consultation with DFO biologists familiar with the study area as well as being knowledgeable about expectations of performance relative to cost. We errored on the side of higher precision for CMR and CEN based assessment methods as, due to significant costs, it makes little sense to implement either unless they are well executed with relatively little error. Each assessment method also requires a different level of effort required to assess a PU (Table 4). This sets up a trade-off between precision and effort between the three assessment methods, where CEN provides the most precise PU estimates of abundance, but requires a substantial effort. AUC requires significantly less effort, but at the cost of lower precision. CMR represents an intermediate trade-off.

Further to the assessment method and effort level, we also considered four different sampling designs to determine which PUs were sampled in a given year (Figure 4). The Random Brood approach treats each broodline within a PU as a unique sampling unit from which to draw a random sample (Figure 4a). Depending on the random draw single sites may have a single, multiple or no broodlines sampled. The second approach (Random PU) randomly chooses PUs (i.e., unique NuSEDS POPIDs) to monitor and then samples all broodlines within each chosen PU (Figure 4b). This second design was chosen as a contrast to the Random Brood approach to judge what gains may be had through a design that considers broodlines separately versus a design that is naïve to broodlines.

The final two designs use an indexing style approach described by English et al. 2006 and English 2016. The index approach assumes that true ordering of PUs by average productivity is known and the selected “indicator” populations are monitored regularly with supporting monitoring to non-indicator populations occurring less regularly. Final, aggregate estimates are determined by adjusting total observed abundance first by the relative weighting of the selected indicator sites and second by the relative weighting of non-indicator sites. For the index approach we considered selecting the local indicator populations independently for each broodline (Index Brood; (Figure 4c) or selecting indicator sites based on the highest average abundance across all three broodiness (Index PU; Figure 4d).

Finally, the effort scenarios under consideration (Table 4) were for the total effort across all three CUs. Effort within each CU therefore depends on how the total effort is allocated. A straight-forward proportional allocation scheme was used based on total number of PUs (i.e., effort is allocated in proportion to the total number of PUs identified within a CU). The only exception to this general rule was that a minimum sampling threshold was enforced for Boundary Bay (Table 4). In instances where total effort was low, Boundary Bay may be allocated less than one site under a proportional allocation scheme. When this occurred a minimum of one site was allocated to Boundary Bay from the Lower Fraser River, which was the region with the highest sampling allocation under a proportional allocation scheme. This approach results in the smallest percent change in sampling coverage.

Statistical Testing

On each simulation iteration, statistical tests were performed to estimate trends for differing management scales and endpoints, and the total escapement was estimated for the LFR MU.

Trend Testing

Trends were assessed at different management scales (i.e., CU and MU) for two different endpoints (i.e., average PU and trends in the aggregate total) and across differing time scales (i.e., 10 and 20 years). Furthermore, tests were also constructed that were either naïve to or controlled for broodline differences. All trends were estimated using linear models or linear mixed effect models depending on whether the average PU or an aggregate trend was being estimated (Table 5). Models that included the *POPID(R)* term were linear mixed effect models with the *POPID(R)* term representing a random effect that accounted for differences between PUs in the average log abundances. Because individual yearly observations within each PU represents a repeat measure, an MA(1) model was used to represent auto-correlation in the residual error. While the simulator did not explicitly include an auto correlation component in the residual error (i.e., $\epsilon_{t,j}$ see Equation 6) the combination of three separate broodlines (Equation 4) and an MA(1) process on the regional yearly error term (i.e., ω_t see Equation 6) to produce yearly observations did produce consistent AR(1) and/or MA(1) signatures in the simulated abundances.

Depending on the assumed conditions of the population under study the COSEWIC status thresholds can vary depending on specifics such as whether the decline is reversible or if the cause of decline has ceased (COSEWIC 2015). As such, we constructed a series of hypothesis tests looking for evidence for any decline, as well as 30%, 50% and 70% or greater declines to match the various COSEWIC thresholds. These tests employed a more classical single-sided statistical test where we are looking for sufficient evidence that an estimated effect exceeds a threshold. A second more relaxed statistical test was also considered where a significant decline was present (classic single-sided test for a non-zero estimated decline) and the 95% confidence level spanned one of the COSEWIC thresholds. These tests indicate that the estimated decline may be consistent with the COSEWIC thresholds, but that more robust statistical evidence is lacking. This alternative is presented to see whether more lenient tests could be used as a harbinger.

Finally, tests were applied across appropriate combinations of assessment methods and sampling designs. For example, by comparing the combination of broodline aware sampling designs and statistical tests against sampling designs and tests ignoring broodline, we can determine whether there were any notable power gains from considering broodlines. Tests were also conducted against data that was trended to match either aggregate or local trend targets depending on the purpose.

Estimating Total Abundances

Total escapement was estimated for the LFR MU based on applying an index sampling and a simple random sampling approach to the LFR MU as a whole. Index sampling selectively applies a weighting scheme that indicates what proportion of the total LFR MU return is represented by the sampled PU. The total LFR MU escapement is then determined by adding the escapements of individual sampled PUs and then expanding by the total weight represented by the sample. Simple random sampling was implemented by randomly selecting PUs then expanding the observed abundance by the total number of PUs in the LFR MU in order to derive an estimate of the total.

Stratification was not considered as it was not applicable to index sampling (i.e., CU membership does need to be considered, in order to determine ranking or weights within the LFR MU). As such, to keep the comparison straight-forward, and to create a simple way to compare the effects of adding additional monitoring sites, sampling was done pooling all PUs across the LFR MU together as a single entity.

RESULTS

SAMPLING DESIGN AND ASSESSMENT METHODS

We evaluated twelve combinations of sampling design and assessment method each with low medium and high precision and effort and tested these against their ability to estimate aggregate escapement to the LFR MU and to detect population declines of varying degrees at each CU and the LFR MU. We found that an index style sampling design outperforms a simple random sample sampling design when the objective is to estimate aggregate escapement (Figure 9) with little advantage (power) gained from sampling broodlines. The greater precision attributed to index sampling design relates to the preferential selection of more productive streams for monitoring (Figure 10). We also evaluated the trade-off between effort and precision in their power to detect a decline 30% or greater and found that AUC and CMR assessment methods can produce similar results (Figure 11). Further, we found that there was little improvement in power to detect declines in aggregate escapement abundance for the most optimistic high effort and high precision scenarios, regardless of assessment method. Specifically, we found that under medium effort and precision combinations across all sampling designs and assessment methods there was little ability to detect even the lowest COSEWIC population status criterion (i.e., 30% or greater decline within 10 years) within 10 years even under a substantial population decline (i.e., 90% within 10 years) (Figure 12). As there were only minor differences between the precision and effort scenario results, we conducted subsequent evaluations of sampling design and assessment methods using only medium precision and effort.

ESTIMATING LFR MU ESCAPEMENT

The ability to estimate escapement to the LFR MU was assessed as this is the primary input for the Coho Fishery Regulation Assessment Model (FRAM). Here we focused on how precision of individual assessments relates to the precision associated with the final LFR MU escapement estimate.

When directly comparing the effect of sampling design on the precision of the aggregate escapement estimate to the LFR MU, there was a clear advantage to an index style sampling design. Under an index style design, and using an assessment method that generates a CV of 15% (medium precision of a CMR), one could achieve a CV of 50% to 25% on the final LFR MU aggregate escapement estimate by monitoring approximately 10 to 15 PUs respectively, while a simple random sampling design would need to monitor between 20 to 60 PUs to achieve the same result (Figure 9). Even with the least precise assessment method (i.e., an assessment CV of 70%) sampling the 15 most productive PUs with an index style sampling design will still achieve a CV on the final LFR MU aggregate escapement estimate within the target range.

The large improvement in precision afforded by index style sampling design can be attributed to the fact that a few highly productive PUs make up the majority of the total escapement (Figure 10). Index sampling typically focuses on sampling effort on the most productive populations first (and herein, assumes they can be assessed), with each successive PU sampled being slightly less productive. This allows a large proportion of the total escapement to be represented with relatively fewer samples (Figure 10a) compared to simple random sampling which selects PUs at random resulting in a more linear progression (Figure 10b). As a result, well designed index sampling can sample nearly 50% of the total LFR MU escapement on average by monitoring the top 10 productive PUs, while simple random sampling would need to sample nearly 70 PUs average to capture a similar proportion of the total return. This difference results in a much lower level of precision with simple random sampling for a given number of PUs monitored.

While a fixed weighting scheme was used, the true weight for any given year can be expected to vary relative to the fixed weights. That is, the proportion of the LFR MU escapement represented by the fixed set of monitoring sites used in an index sampling scheme can be expected to vary between years. This weighting uncertainty was found to be a function of how many PUs were sampled and the proportion of the LFR MU escapement represented by fixed weighting scheme (Figure 13) and included when comparing final survey precision (i.e., Figure 9).

A summary of the yearly weighting variability, by PUs sampled and the proportion of the LFR MU escapement represented by the fixed weighting scheme is provided as a lookup table for future practitioners (Table 6). Because yearly escapement is typically log normally distributed, the additional variability associated with a fixed weighting scheme could lead to bias. While a theoretical possibility, the amount of realized bias compared to a dynamic weighting scheme was quite small (Figure 14). Furthermore, performance advantages of a dynamic yearly weighting scheme were also quite small compared to a fixed weighting scheme (Figure 15). Both approaches showing similar levels of weighting variability and a similar proportion of the LFR MU escapement described by a given sampling effort.

TREND MONITORING

Trend monitoring – MU and CU

When declines were simulated over a ten-year period we found that the top performing sampling designs and assessment methods combinations only had 80% power to detect any decline in aggregate escapement when the true decline was over 75% over the same period (Figure 12). This held true across each CU and the LFR MU, effectively indicating that none of the tested design combinations provided sufficient power to provide management with timely information that a CU or the LFR MU was in any decline. During this simulated ten-year period, we found little difference in the power to detect a decline between any of the three assessment methods or sampling designs at any given level of true population decline. The exception is the LILL CU, where a census style assessment coupled with either a random PU or random broodline sampling design outperformed all others (Figure 12).

When aggregate abundance was simulated to decline at the same rate over twenty years we found that the power to detect a decline improved for each CU and the LFR MU for each of the twelve combinations of sampling design and assessment method (Figure 16). Further, apart from the LILL CU, there appear to be clear trade-offs between the assessment method deployed and the true population decline such that during low levels of population decline, a census style assessment provides the most power to detect the decline for the BB and LFR CU as well as the LFR MU, while at higher levels of population decline, an AUC style assessment provides the best power to detect a decline. Under all conditions, however, a census type assessment remains the preferred method to detect a decline in the LILL CU (Figure 16).

Over the twenty-year time horizon there was sufficient power (i.e., a power of 80% or greater) to detect the minimum COSEWIC threshold status of threatened (30% decline or greater decline) when the true population decline was in excess of 75%. Larger total declines (i.e., 90% or greater) were required to detect more stringent COSEWIC thresholds (i.e., 50% or greater and 70% or greater). These results suggest that assessing status using the COSEWIC criteria based on trends in total abundance requires scenarios of much larger population declines over extended periods of time or significantly more effort that has ever been deployed to monitor this LFR MU.

Trend monitoring – Population Units

As an alternative to assessing decline on the aggregate trend we assessed decline of the average PU trend. The aggregate trend can be viewed as weighting PU trends by their respective contribution to the total abundance while the average PU trend weights each PU equally. This resulted in substantial improvements in power for detecting trends on a given time frame (i.e., within 10 years; Figure 17). On average, AUC and CMR assessment methods had similar power to detect trends under most sampling designs, with AUC having marginally better power to detect declines at the PU level (Figure 17). Directly comparing the declines in escapement at the PU and the aggregate level under the same set of conditions (i.e., the AUC assessment method and Random Brood survey sampling) illustrates the outperformance (improved power) of detecting a decline at the PU level rather than the aggregate (Figure 12 vs. Figure 17). Most CUs and the LFR MU showed sizable gains in power using the average PU trend, with the exception of Boundary Bay which only showed modest gains in power.

The difference in power for detecting trends for aggregate (CU/MU) versus the average PU trend can be attributed largely to the fact the two approaches measure slightly different population attributes. Aggregate (CU/MU) tends to be more sensitive to the trends exhibited by a few highly productive PUs, effectively masking trends exhibited in lower productivity PUs. As such, the aggregate CU/MU) is largely an indicator of highly productive PU trends. PUs that contribute little to the total abundance can exhibit extreme declines without any notable shift in the aggregate (CU/MU) trend. In the context of the simulation study, trends were assigned at random to each PU from a normal distribution, therefore for a given aggregate (CU/MU) trend exhibited, the average PU trend was on average more extreme (Figure 18). The physical characteristic of each CU will also influence this observed discrepancy. CUs with higher inter-PU trend variability will exhibit a larger average discrepancy (e.g., LILL; Figure 18), CUs with more PUs will also exhibited a larger average discrepancy (e.g., BB vs LFR; Figure 18).

For a given assessment method (i.e., AUC under medium effort and precision scenarios), the ability to detect the average PU trend was highest at the MU level, followed by LFR, LILL and BB CUs trends (Figure 19). This ordering was closely associated with the total number of PUs monitored. The ability to monitor PU trends can also be impacted by how PUs were selected. For index sampling if PUs were selected independent of the trend the power to detect PU trends was comparable to randomly selected PUs (Figure 20a). However, if index sites were not chosen independently from the PU specific trends (i.e., PUs were chosen after trends were applied) then a notable difference in power emerged (Figure 20b) indicating that PU selection needs to be independent of any mechanisms driving trends.

Finally, additional gains in power could be obtained by focusing on sampling broodlines within PUs rather than PUs themselves (Figure 21). The benefit to sampling broodlines was, however, also found to also be dependent on how broodlines were modelled. During testing it was noted that a simpler simulator without any associations between broodlines within a PU however produced very little advantage in power to brood line sampling.

DISCUSSION

The simulation study revealed that sampling designs and assessment methods need to be tailored to specific management objectives, a conclusion supported by others (Holt et. al. 2011 and Peacock and Holt 2012). Within the context of monitoring Lower Fraser Coho, sampling designs will need to be created to achieve specific goals such as estimating escapement or trend monitoring within the LFR MU. Hybrid or omnibus designs attempting to achieve both objectives simultaneously are not viable due to the differing requirements of each objective. Escapement estimation will be best served by index sampling designs, where the PUs with the highest average productivity are monitored each year and an adjustment is made to account for escapement to those PUs that are not assessed. Due to the skewed nature of PU productivity, this makes the most efficient use of available effort by targeting the most productive PUs first and can reduce the required effort by up to a third relative to the random selection of PUs. Trend monitoring, in contrast, will be best assessed by randomly selecting PUs to monitor over time (Peacock and Holt, 2012). Random selection provides an un-biased portfolio of streams to monitor, thus ensuring that PUs with a suite of different characteristics are included.

Mixing sampling designs (i.e., index and randomly sampled PUs) is also problematic from a technical standpoint. Determining the appropriate adjustments for the total LFR MU escapement becomes problematic as the relative productivity of the randomly sampled PUs will not be known. Furthermore, including non-randomly selected PUs (i.e., index sampling) with randomly selected PUs for trend monitoring will require strong assumptions on the independence of trends from underlying PU-specific productivity. Both caveats are likely to undermine the primary goals of each program, providing little benefit to pursuing a hybrid or omnibus type design. Managers will therefore need to design separate studies for each objective. Given the limited survey effort available, one objective will need to be prioritized, or potentially to the exclusion, of the other.

Once basic prioritizations have been determined further challenges exist within each sampling design approach. A specific challenge to implementing an index style approach for the LFR MU include the fact that, due to the poor escapement record, the relationship(s) between PUs selected for assessment and those not selected is uncertain, thus these relationships would have to be developed prior to implementing an index style sampling design or the general results from the simulation study will be need to be used in its place (see further discussion in Estimating LFR MU Escapement). On a more practical level, it is likely that the physical conditions (width, discharge, visibility, length) of the most productive streams (Salmon River, Pitt River, Chilliwack River, etc.) are not amenable to supporting AUC style assessments. For these larger rivers, a CMR or census style assessment method would likely be more appropriate, however the costs of implementing these types of assessments on such a large scale could be prohibitive. Our evaluation of sampling designs and assessment methods did not evaluate the effect of using a mixture of assessment methods. Trend monitoring, which was found to be best assessed by randomly selecting PUs to monitor over time, faced complications over how to best measure trends. Monitoring trends in aggregate showed low power and require long timelines before trends could be detected. This was primarily the result of aggregate measures of escapement of PU-specific trends and PU-specific exponential growth models which resulted in noisy aggregate escapement metrics, which reduce the ability to detect temporal trends. In contrast, estimating the average PU trend showed much higher power and could more than halve the timeline required to detect a decline. However, the approach may be incompatible with COSEWIC assessment requirements, which may limit the applicability of this type of approach.

ESTIMATING LFR MU ESCAPEMENT

If estimating aggregate escapement to the LFR MU is a priority managers will need evaluate trade-offs between: 1) The desired final precision of the aggregate estimate; 2) The expected precision on the escapement estimate of each PU (i.e., assessment precision), and; 3) The expected effort (budget) available. Once these have been evaluated, management can then determine the total number of PUs that need to be assessed (Figure 9). With an index style approach, monitoring the 10-15 most productive PUs appears to generate an aggregate estimate within the target CV range of 25-50% regardless of assessment precisions tested. This would suggest favouring a simpler assessment method that may have a slightly lower precision (i.e., higher CV), but will allow for more PUs to be monitored and/or costs to be lowered. Holt et al. (2011) similarly describe that reducing the amount of missing data (i.e. sampling more PUs) could be better than obtaining more precise estimates. If more precise estimates of the LFR MU escapement are required (i.e., < 25% CV) then the precise assessment method becomes more critical, in addition to requiring additional PUs to be monitored.

Despite the advantages of deploying an index style sampling design, estimating the CV on the final LFR MU escapement can be problematic. For an index design, uncertainty in the individual PU weights must be included in the final estimate of uncertainty. The most feasible weighting scheme will be a fixed selection and weighting scheme, where the set of PUs selected to assess are standardized and weightings are estimated based on the average productivity over a standardized time-period such as 10-years. However, on any given year, we can expect the true proportion of the LFR MU escapement represented by a set of PUs selected to differ from the proportion of the LFR MU represented estimated based on the average productivity. In some years, the average weighting may be an underestimate, in others an over estimate. In this study, the final LFR MU CV incorporated this uncertainty by applying corrections based on empirical results from the simulator where variability in the yearly weights for a set of PUs selected based on average productivity over a 10-year period was determined by the number of PUs sampled and the average proportion of LFR MU represented by the set of PUs (Figure 13). For each set of PUs sampled (e.g., a set of 10 PUs monitored each year, selected based on their average productivity) the weighting variability (i.e., year-to-year variability in the LFR MU proportion represented by the set of PUs being monitored) was found to vary linearly with the average LFR MU return proportion the set of PUs represent with the slope of the relationship varying by the number of PUs in the monitoring set. These relationships were used to predict the year-to-year weighting variability, which was then incorporated into the final precision on the LFR MU escapement. Studies looking to employ index sampling will either need to adopt these approximate corrections for weighting uncertainties or develop a more concise statistical theory to account for uncertainty in weighting schemes.

A second potential issue with selecting a fixed set of monitoring PUs and using a fixed weighting scheme is potential bias compared to dynamically determining weights each year (i.e., a dynamic weighting scheme). While the latter is not a feasible approach (it would require perfect knowledge of annual escapement to each PU), the two approaches can be compared to evaluate the amount of potential bias that can result from a fixed weighting scheme. We evaluated the potential for bias and found that the realized bias was quite small (Figure 14). Both approaches on average described a nearly identical proportion of the total LFR MU escapement, suggesting that there is not a practical difference between the two weighting approaches. As such, we do not believe a bias correction is required when using a fixed weighting scheme each year.

While not feasible, as it would require perfect knowledge, it may also be of interest to compare the performance of a fixed selection and fixed weighting scheme to a dynamic selection and dynamic weighting scheme, where the top producing PUs are selected each year and the appropriate weightings determined. While a dynamic selection and weighting scheme was found to describe a larger proportion of the LFR MU and had a lower weighting variability, a fixed selection and weighting showed remarkably similar performance (Figure 15). While a dynamically selection and weighting scheme would theoretically provide a performance gain, the realized gains appear to be quite small suggesting that the practical approach (i.e., a fixed selection and weighting scheme) will be a good option. As such, practitioners will want to focus on developing a robust fixed weighting scheme, rather than attempt or be concerned with deriving a dynamic weighting schemes for each survey year.

While index sampling appears to be the most applicable technique for estimating escapement, the main technical barrier remains the ability to derive a defensible fixed weighting scheme that can be used to expand observed escapements into an estimate for the total escapement. Ideally, these weighting schemes require knowledge on the average productivity of all PUs in the LFR MU. This is not currently known, and it may never be known in full. That said, we may be able to relax this requirement when deriving weightings. First we would suggest that it may be possible to select the most productive PUs within the LFR MU to monitor without knowing the average productivity or the relative weightings. This could be accomplished by combining multiple sources of information such as local knowledge and historical escapement records. Assuming the simulation model provides a reasonable approximation for the PU-to-PU variation in escapement across PUs in the LFR MU, it should be possible to use relationships derived from the simulation study to determine the approximate weightings the selected PUs represent relative to the LFR MU as a whole. Because the average productivity of the sites is not known, the full distribution of weightings exhibited (i.e., Figure 10a) will need be considered in addition to the year-to-year variation in weightings (Table 6). The impact of both on the final LFR MU escapement precision could be considered in tandem by using a Monte Carlo type approach and would represent a novel merging of simulation and empirical results in order to determine the final survey precision.

TREND MONITORING

Trend monitoring in the LFR MU presents a number of problems in terms of efficacy, available effort and appropriate metrics used to monitor population trends. The COSEWIC (2015) assessment guidelines clearly states that if abundance estimates are to be used to set a population status, the trend should be measured in terms of a decline in total number of mature individuals (i.e., aggregate escapement). Because Coho Salmon are managed at the MU level, this implies the use of aggregate trends at these management levels. However, the simulation study demonstrated that we have very poor power to detect aggregate trends at any of the management levels (i.e., CUs or the LFR MU).

The aggregate abundance is the composite of escapements across a variety of PUs, as such, there is high process noise which can limit the ability to detect trends at the aggregate level on a reasonable time scale (e.g., within 10 years). Furthermore, aggregate trends also disproportionately represent high productivity sites over lower productivity sites. It is not unreasonable to assume that high productivity sites may not exhibit the same degree of declines as lower productivity sites. For example, a higher productivity PU may have less environmental degradation than a lower productivity PU. This makes the aggregate trend a more representative measure of the status of top producing sites rather than all sites within a given management unit. Indeed, Peacock and Holt (2012) found the index method especially poor at detecting changes in population characteristics such as contractions in spawning distribution unless survey coverage was almost complete. Furthermore, this association should also preclude the use of PUs selected for estimating LFR MU escapements by index sampling from the sites used to monitor local trends as these sites by the nature of their productivity may exhibit less extreme trends and therefore under represent the trends exhibited in the population as a whole.

Extending the monitoring time-period to 20 years did, however, result in improved power (Figure 16). For this testing scenario the population declines were extended for a period of 20 years. This resulted in more years of data in which to detect an effect and larger overall true declines. For example, a population decline of 50% within 10 years would produce a total decline of 75% within 20 years. Holt and Cox (2008) similarly found that extending the monitoring time period to 20 years resulted in improved probability of detecting a population decline, though probability to detect the decline varied with assessment method.

In contrast, the average PU trend metric exhibited more favourable power to detect trends. Unlike the aggregate trend, the average PU trend weights the trends exhibited by each PU equally, allowing it to be more sensitive to the trends exhibited by low productivity sites. This in turn allowed the average PU trend metric to be more sensitive to instances of general decline across the larger group of PUs. This potentially allows the average PU trend metric to highlight population trends before they are exhibited at the aggregate level.

This difference in trend metrics is the consequence of trend variability across PUs combined with an exponential population growth model being used within each PU. PUs exhibiting more extreme declines will rapidly contribute less to the total abundance and therefore have a smaller influence on the aggregate trend. PUs with less extreme trends can rapidly over time contribute more to the total abundance, thereby exerting a stronger influence on the aggregate (CU/MU) trend. Both components are required for this discrepancy between metrics. If each PU did not exhibit trend variability there would be no difference between the average PU trend and the aggregate (CU/MU) trend. Furthermore, if PU escapement abundances changed linearly, rather than exponentially, over time then any discrepancy between the two metrics would disappear as additional PUs were sampled.

The discrepancy was further accentuated for the LILL CU which had higher inter-PU trend variability than the BB and LFR CU, and for CUs with higher total number of PUs. This can be observed in the larger discrepancy between average local decline and aggregate decline exhibited by LILL CU relative to BB CU or LFR CU (Figure 18). While the BB and the LFR CU did not differ in trend variability, the two CUs did differ in the number of PUs. Because the LFR CU possessed a much higher number of PUs there was a higher probability of getting higher productivity sites on any given simulation iteration. This resulted in a larger discrepancy between the average PU trend and the aggregate trend exhibited by LFR CU relative to BB CU.

The discrepancy between the two trend monitoring metrics highlights important considerations for managing the status of a population. Because trends in aggregate abundance tend to disproportionately represent high productivity sites, lower productivity PUs can start to undergo declines without adversely affecting the aggregate. If the remaining highly productive sites also undergo similar declines (e.g., better environmental conditions observed at high productivity sites were only able to buffer larger scale changes for a limited period of time) this could result in a situation where the population can undergo a rapid and precipitous decline before management has an opportunity to respond. Within the context of this study, the ability to detect aggregate trends that were compliant with COSEWIC guidelines only occurred under situations of high total population declines (e.g., a true population decline 75% or greater decline was required to statistically demonstrate aggregate decline of 30% or greater on a 10 year time horizon). As such, reliance only on aggregate measures to manage the population makes it possible for general declines across PUs to go largely unnoticed until the population hits a substantial tipping point. Thus, monitoring aggregate trends in abundance makes proactive management problematic as the signal of a decline may only appear once the decline is well established. In contrast, managing with the average PU trend could allow for earlier detection of downward trends before they affect the aggregate escapement. Taken together, we suggest that the COSEWIC assessment metrics, while important for setting the status of the population, may not be the best the most appropriate metric for monitoring and setting manage objectives.

The study largely considers theoretical issues associated with the selection of and assessment of PUs. Our evaluation of sampling designs and assessment methods did not evaluate the effect of using a mixture of assessment methods, nor the applicability of assessment methods across all PUs. In practice, multiple assessment methods are likely to be utilized based on local knowledge, stream attributes and personnel effort, thus our results should be used as a guide only. In terms of practical design considerations, practitioners may wish to focus PU sampling on the LFR CU, leaving the LILL CU to census style sampling and forgo monitoring the BB CU. The LILL CU showed the highest inter-PU trend variability which favoured a census style assessment method for monitoring aggregate trends in escapement. It is also the only CU with a natural bottle neck which makes census style monitoring more practical. The remaining CU, LFR, will be best served by the random selection of CUs for trend monitoring.

CONCLUSIONS AND RECOMMENDATIONS

There is no one-size-fits all sampling and sampling design that can be applied to monitor total escapement and trends in escapement. An appropriate sampling design for LFR Coho Salmon needs to be tailored to specific management objectives, and where there are multiple objectives, appropriate and sufficient resources will need to be allocated or objectives will need to be re-evaluated.

Adequate monitoring of Coho Salmon in the LFR MU will require significant and committed investment by DFO. Initiating a monitoring program that will meet the needs of the Wild Salmon Policy, the Pacific Salmon Treaty and local (First Nation) interests will require a coordinated, focused and sustained approach by DFO and its partners. A reference to the significant investment required for adequate monitoring can be found by looking at the Interior Fraser River (IFR) Coho Salmon MU which was designated as Endangered by COSEWIC (COSEWIC 2002) due to significant declines in abundance, but was recently re-assessed as Threatened (COSEWIC 2016). Here, no fewer than two mark recapture programs (since 1993) and up to seventeen counting fences (1998) and one fishway (1998) have operated (Irvine et al. 1999). The IFR MU has thus received significant and sustained effort and resources that has not been received by the LFR MU which, in the same time period, has had its only fence operation cancelled (Salmon River), has only had a handful of mark recapture studies (Upper Pitt River and Salmon River), and since 2002 has had two full years where DFO had no funds to support any stream surveys (2003, 2007. Thus, to adequately monitor escapement to the LFR MU, we recommend that DFO and its partners first agree on management objectives and second, commit annual dedicated funding that is sufficient to achieve the objectives.

The work discussed herein was limited to proven sampling designs and assessment methods used to monitor Pacific Salmon. However, considering the poor data on record for the LFR MU, and the uncertainty of future funding priorities, a unique opportunity is provided to DFO to be creative in how best to meet their objectives of estimating escapement to the LFR MU and monitoring trends, amongst others. Specifically, should monitoring the IFR Coho MU remain a top priority (and thus compete for funds), it may be worthwhile to evaluate and/or develop alternatives such indexing escapement of the LFR MU to that of the IFR MU.

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TABLES

Table 1. Escapement estimate class counts A) and percentages B) for each CU.

A)

Conservation Unit	**Escapement Estimate Quality**								
	1	**2**	**3**	**4**	**5**	**6**	**Unknown**	**Relative**	**Total**
Boundary Bay			2		1			4	7
Lower Fraser River	28	21	248	22	43	2	99	8	471
Lillooet			60	37	9		15		121

B)

Conservation Unit	**Escapement Estimate Quality**								
	1	**2**	**3**	**4**	**5**	**6**	**Unknown**	**Relative**	**Total**
Boundary Bay			29%		14%			57%	100%
Lower Fraser River	6%	4%	53%	5%	9%	0%	21%	2%	100%
Lillooet			50%	31%	7%		12%		100%

* Type 3 data quality in NuSEDS has been changed to Type 5 until further review (L.Ritchie, pers. Comm)

Table 2. Agencies within the LFR MU contacted for additional escapement data.

Agency Type	Agency Name	Name	Supplemental Data
Government	Chehalis First Nation	Kim Charlie	
Government	Katzie First Nation	Rick Bailey	no
Government	Kwantlen First Nation	Les Antone	no
Government	Kwikwetlem First Nation	Ed	No
Government	Matsqui First Nation	Brenda	n/a
Government	New West First Nation	General	no
Government	Semiahmoo First Nation	General	no
Government	Musqueam First Nation	Willard Sparrow	Yes
Government	Lower Fraser Fisheries Alliance	Aidan Neill	No
Government	Douglas First Nation	Randall Charlie	n/a
Government	Lil'wat First Nation	DFO (Tracy Cone)	n/a
Government	DFO	Maurice Scott	No
Government	Metro Vancouver	Heidi Walsh	No
Industry	BC Hydro		Yes

Table 3. Combinations of sampling design, assessment method, precision and effort

Survey Design	**Sampling Unit**	**Assessment Method**	**Precision (CV)**	**Effort (person days)**	
Index Sampling	Population Unit	AUC	Low (70%)	Low (184)	
				Medium (360)	
				High (578)	
			Medium (50%)	Low (184)	
				Medium (360)	*
				High (578)	
			High (30%)	Low (184)	
				Medium (360)	
				High (578)	
		Capture-Mark-Recapture	Low (20%)	Low (184)	
				Medium (360)	
				High (578)	
			Medium (15%)	Low (184)	
				Medium (360)	*
				High (578)	
			High (5%)	Low (184)	
				Medium (360)	
				High (578)	
		Census	**High (2.5%)**	**Medium (360)**	*
				High (578)	
Index Sampling	Broodline	…	…	…	
Random Sampling	Population Unit	…	…	…	
Random Sampling	Broodline	…	…	…	

* Indicates the precision and effort scenario used for general comparisons

Table 4. Effort allocation across study CUs by assessment method and effort scenario. Sites per year is the total effort applied across all three regions of interest (i.e., BB, LFR, and LILL). A modified proportional allocation scheme was used, where minimum sampling effort was enforced for BB.

	Effort Scenarios			**Effort Allocation**			
Assessment Method	**Name**	**Person Days**	**Days per Assessment**	**Total**	**BB**	**LFR**	**LILL**
AUC	Low	184	10	18	1	14	3
	Medium[1]	360		36	1	29	6
	High	578		58	2	47	9
CMR	Low	184	20	9	1	7	1
	Medium[1]	360		18	1	14	3
	High	578		29	1	24	4
CEN	~~Low[2]~~	~~184~~	120	~~2~~	–	–	–
	Medium[1]	360		3	1	1	1
	High	578		5	1	3	1

[1] Effort scenario used for general comparisons.

[2] Effort scenario was not considered as all regions cannot be sampled within each year.

Table 5. Linear models used to test for trends in spawner abundances.

Trend Target	**Regional Scope**	**Brood Aware**	**Linear Model**
Aggregate	CU	No	*Log(TotalSpawners) = Year:CU*
Aggregate	MU	No	*Log(TotalSpawners) = Year*
Aggregate	CU	Yes	*Log(TotalSpawners) = Brood + Year:CU*
Aggregate	MU	Yes	*Log(TotalSpawners) = Brood + Year*
PU	CU	No	*Log(LocalSpawners) = CU + Year:CU + POPID(R)*
PU	MU	No	*Log(LocalSpawners) = Year + POPID(R)*
PU	CU	Yes	*Log(LocalSpawners) = CU:Brood + Year:CU + POPID(R)*
PU	MU	Yes	*Log(LocalSpawners) = Brood + Year + POPID(R)*

Note: The term *POPID(R)* represents a random effect term with an MA(1) structuring.

Table 6. LFR MU weighting variability (SD) as a function of the proportion of escapement to the LFR MU and the number of PUs sampled.

	Number of PUs Sampled																
Escapement Proportion	**1**	**2**	**3**	**4**	**5**	**7**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**50**	**60**	**70**	**80**
0.00-0.05	0.071	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.05-0.10	0.088	0.041	0.063	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0.10-0.15	0.106	0.064	0.075	0.044	-	-	-	-	-	-	-	-	-	-	-	-	-
0.15-0.20	0.123	0.088	0.087	0.061	0.079	-	-	-	-	-	-	-	-	-	-	-	-
0.20-0.25	0.141	0.111	0.099	0.078	0.088	0.048	-	-	-	-	-	-	-	-	-	-	-
0.25-0.30	0.159	0.134	0.111	0.095	0.097	0.064	0.063	-	-	-	-	-	-	-	-	-	-
0.30-0.35	0.176	0.157	0.124	0.111	0.105	0.079	0.070	-	-	-	-	-	-	-	-	-	-
0.35-0.40	0.194	0.181	0.136	0.128	0.114	0.094	0.077	0.040	-	-	-	-	-	-	-	-	-
0.40-0.45	0.211	0.204	0.148	0.145	0.123	0.109	0.084	0.051	-	-	-	-	-	-	-	-	-
0.45-0.50	0.229	0.227	0.160	0.161	0.131	0.124	0.091	0.062	0.040	-	-	-	-	-	-	-	-
0.50-0.55	0.246	0.251	0.172	0.178	0.140	0.140	0.098	0.073	0.050	0.034	-	-	-	-	-	-	-
0.55-0.60	0.264	0.274	0.185	0.195	0.149	0.155	0.105	0.084	0.060	0.043	-	-	-	-	-	-	-
0.60-0.65	0.281	0.297	0.197	0.212	0.158	0.170	0.112	0.094	0.070	0.053	0.049	-	-	-	-	-	-
0.65-0.70	0.299	0.320	0.209	0.228	0.166	0.185	0.119	0.105	0.080	0.062	0.052	0.035	0.025	-	-	-	-
0.70-0.75	0.316	0.344	0.221	0.245	0.175	0.201	0.126	0.116	0.090	0.071	0.055	0.043	0.033	-	-	-	-
0.75-0.80	0.334	0.367	0.233	0.262	0.184	0.216	0.133	0.127	0.100	0.081	0.057	0.052	0.041	0.029	-	-	-
0.80-0.85	0.351	0.390	0.245	0.278	0.192	0.231	0.140	0.138	0.109	0.090	0.060	0.060	0.049	0.032	0.024	-	-
0.85-0.90	-	-	0.258	0.295	0.201	0.246	0.147	0.149	0.119	0.099	0.063	0.068	0.057	0.035	0.025	0.019	-
0.90-0.95	-	-	-	-	-	-	0.154	0.159	0.129	0.109	0.065	0.076	0.065	0.037	0.026	0.018	0.015
0.95-1.00	-	-	-	-	-	-	-	-	-	-	0.068	0.084	0.073	0.040	0.027	0.018	0.012

FIGURES

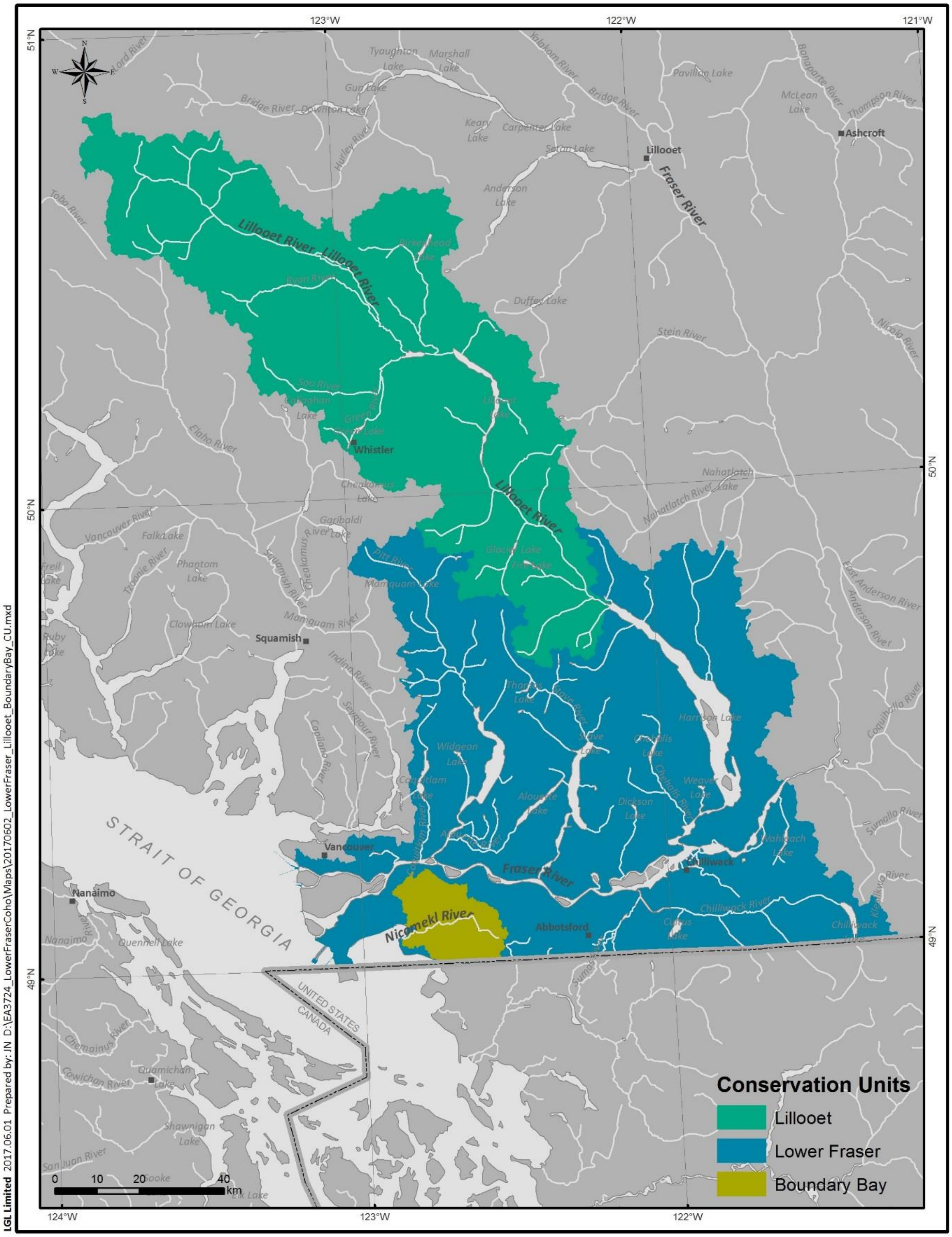

Figure 1. Map of the Coho Salmon LFR MU with each CU delineated.

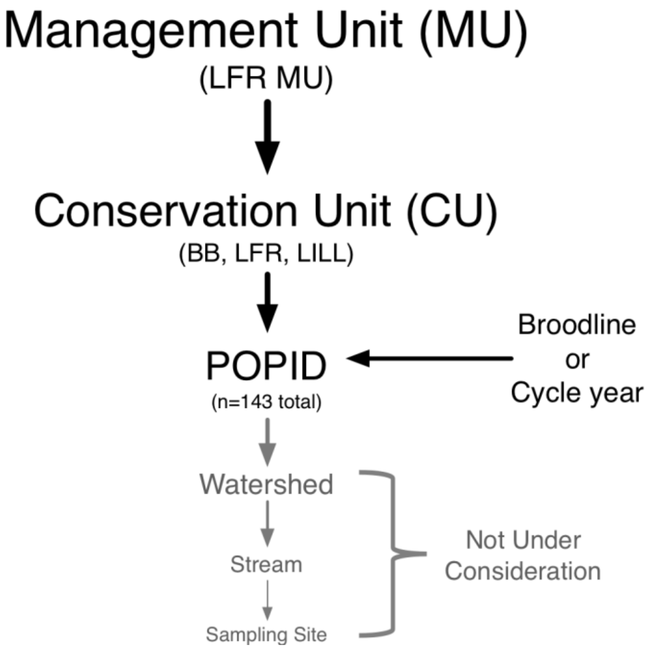

Figure 2. Simulation study scope considers the optimal selection of POPIDs (both within study CUs and across the MU) over the course of different time horizons (e.g, 10 and 20 years).

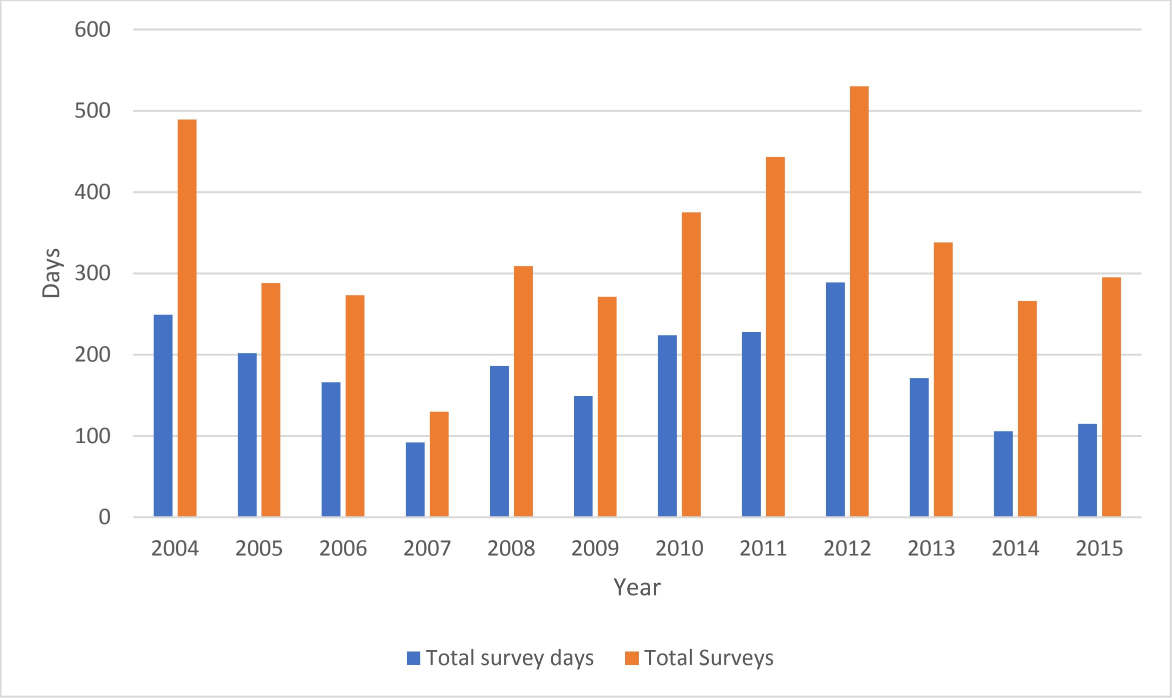

Figure 3. Annual effort (survey days) by all agencies and the total number of surveys conducted within the LFR MU 2004 – 2015

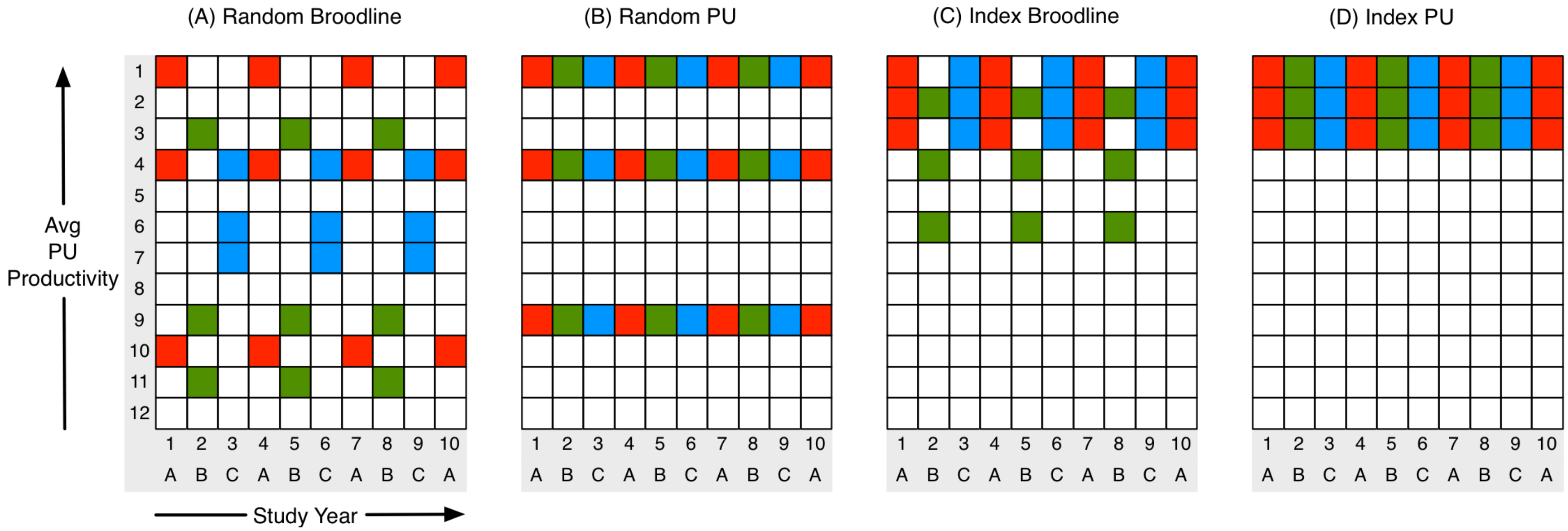

Figure 4. Schematics of sampling designs under consideration include A) random sampling of each unique broodline within each PU, B) random sampling of each PU, C) the index approach applied to each broodline independently, and D) the index approach applied at the PU level.

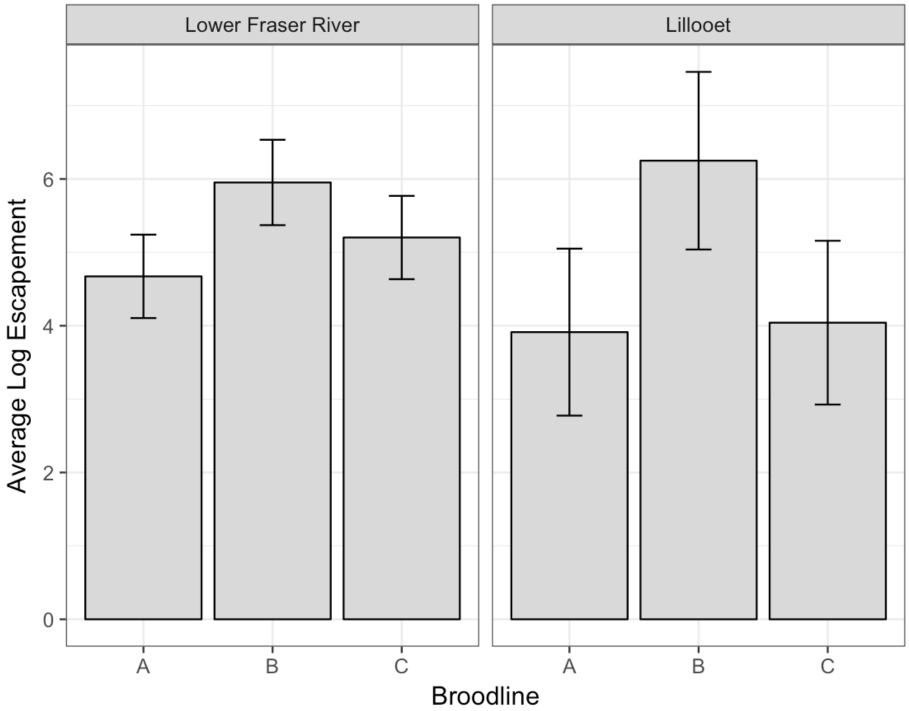

Figure 5. Estimated average log escapement for each of the three Fraser Coho broodlines estimated independently within each region. Estimates were based on a revised data set containing the longest consecutive series. Broodline A corresponds to the 1997 parental line, while Broodlines B and C correspond to the 1998 and 1999 broodlines respectively.

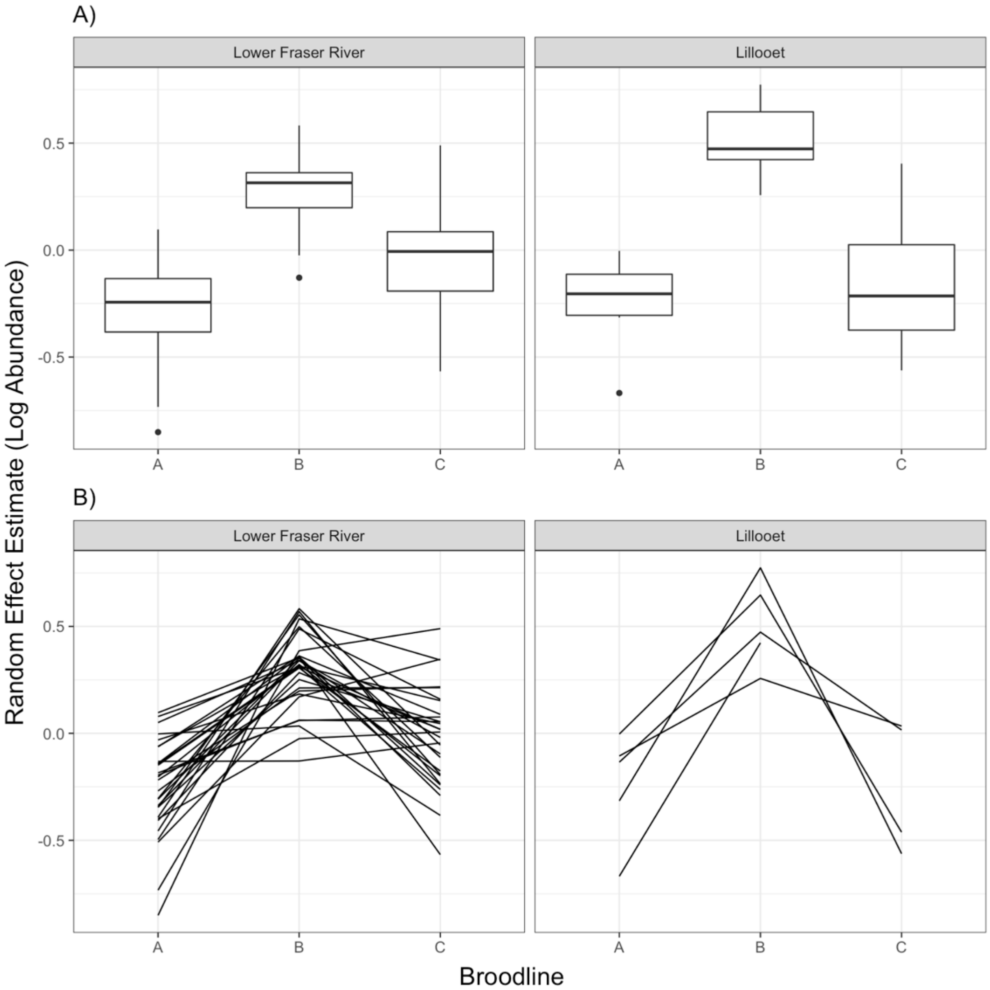

Figure 6. Summary of broodline effects estimated at the site level. Broodline effects were estimated as differences from the main site and region effect, based on a nested random effects model. Random effects were separately estimated for each broodline within each site (i.e., PU) and are displayed as A) distribution of estimates and B) line plot connecting estimates within each PU.

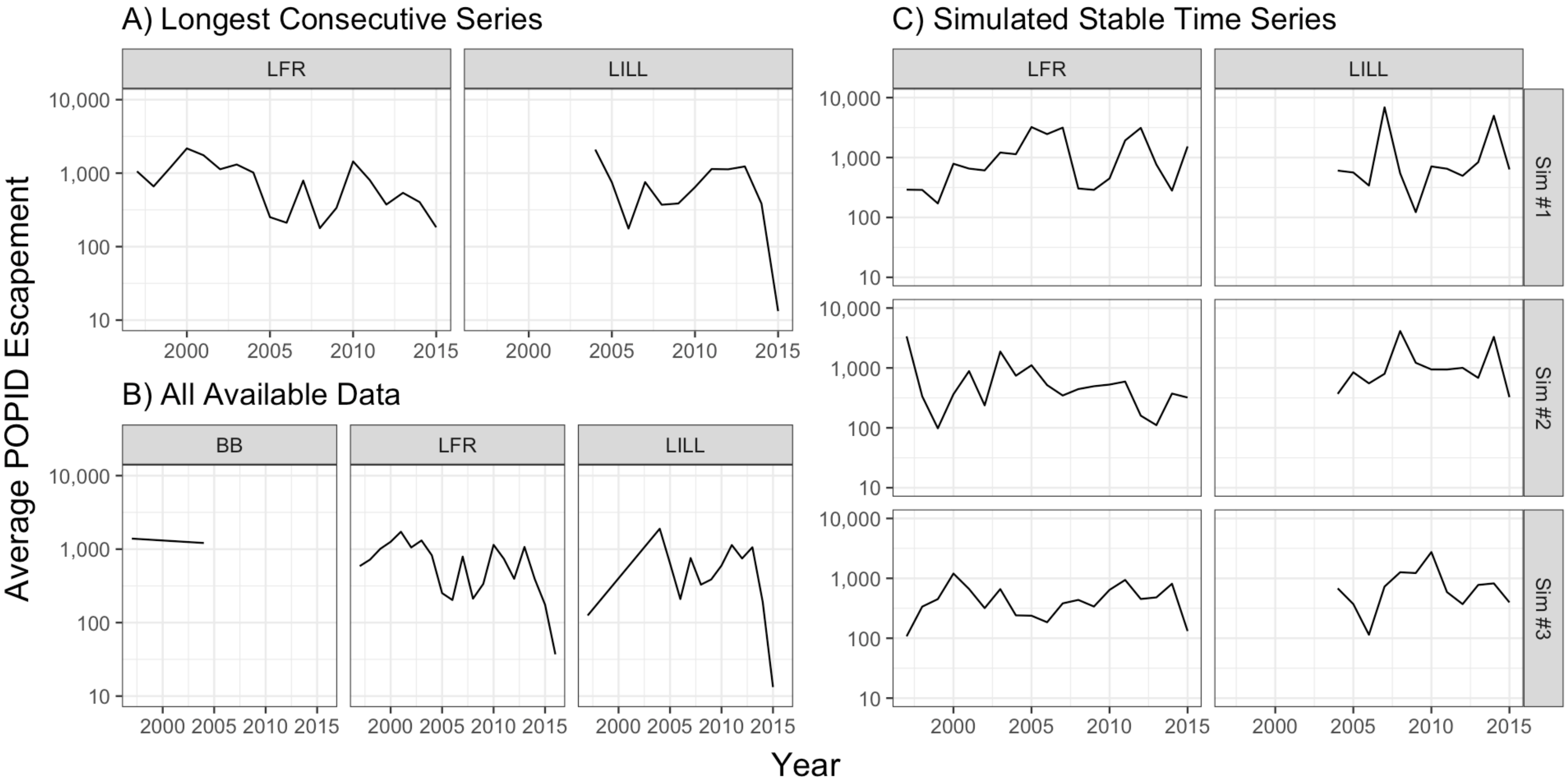

Figure 7. Example A) observed average escapement time series using the longest consecutive series and B) all available data, along with C) simulated time series for the same period.

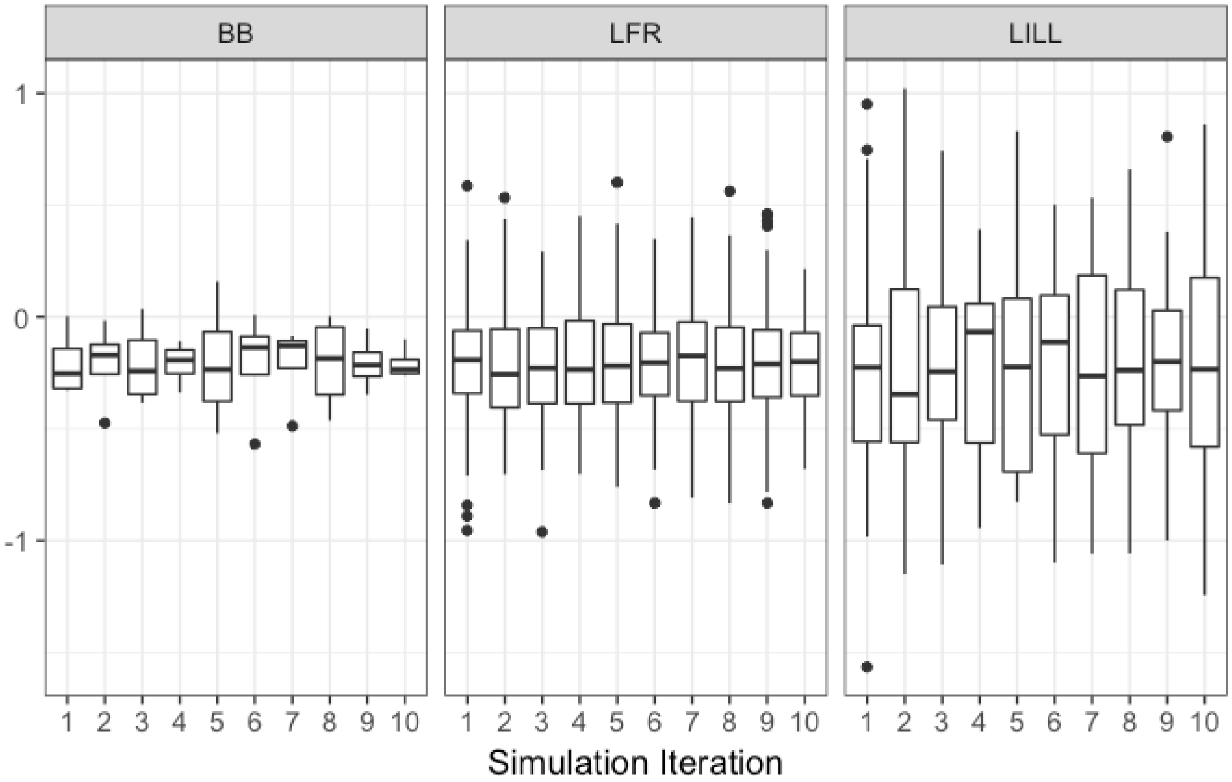

Figure 8. Example of the inter-PU variation in trends by CU for 10 simulation iterations where the trend has not been centered.

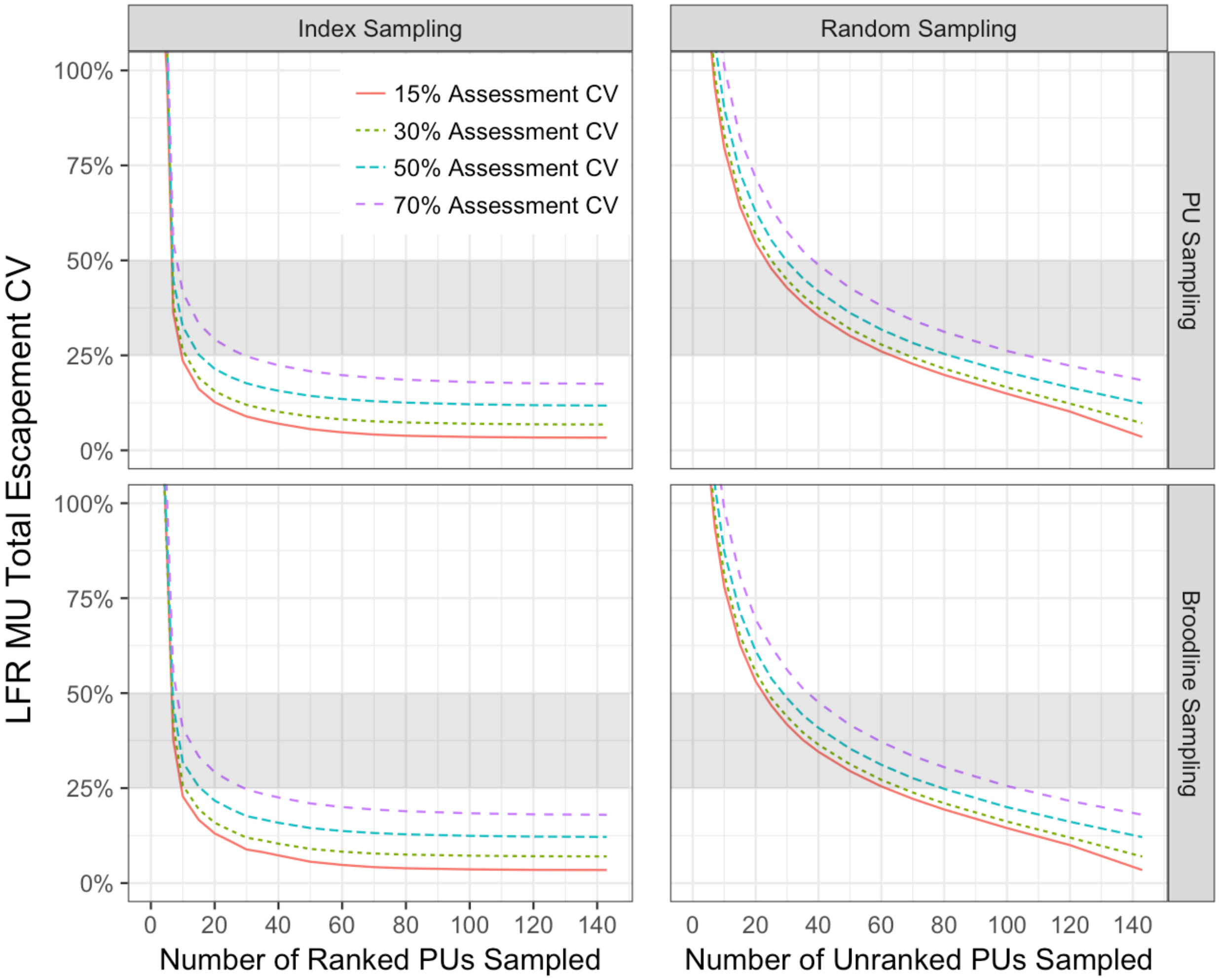

Figure 9. Comparison of the impact of sampling approach (i.e. index or random sampling) and sampling unit (i.e., broodline or PU sampling) on the precision of final LFR MU escapement estimate for different assessment precisions. The grey shading indicates the target range for an acceptable CV on the estimate of total LFR MU escapement.

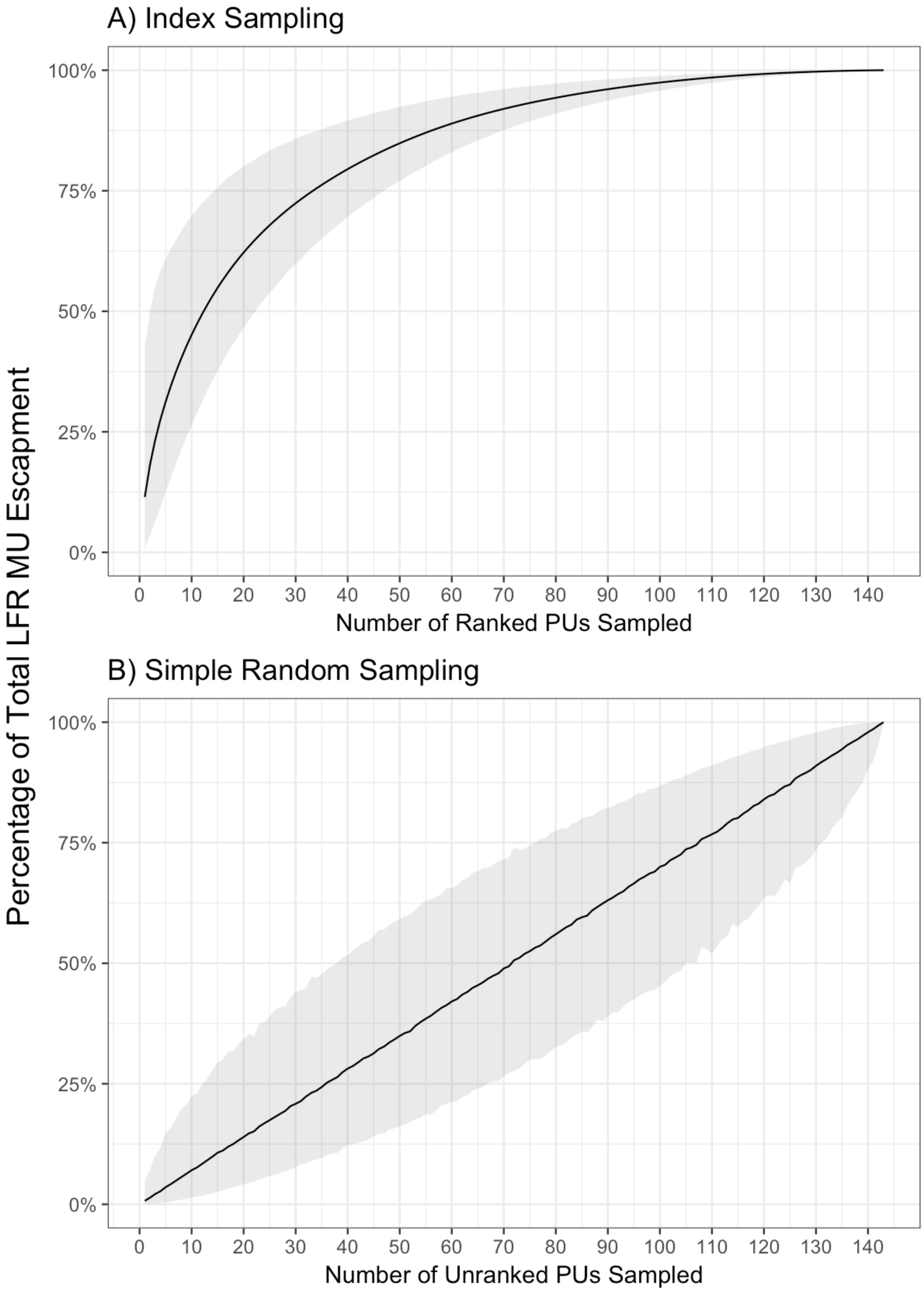

Figure 10. Percentage of escapement via Index (A) or SRS (B) sampling design. Line indicates the average percentage of escapement, while grey shading indicates the 2.5% and 97.5% percentiles from 2,500 simulations.

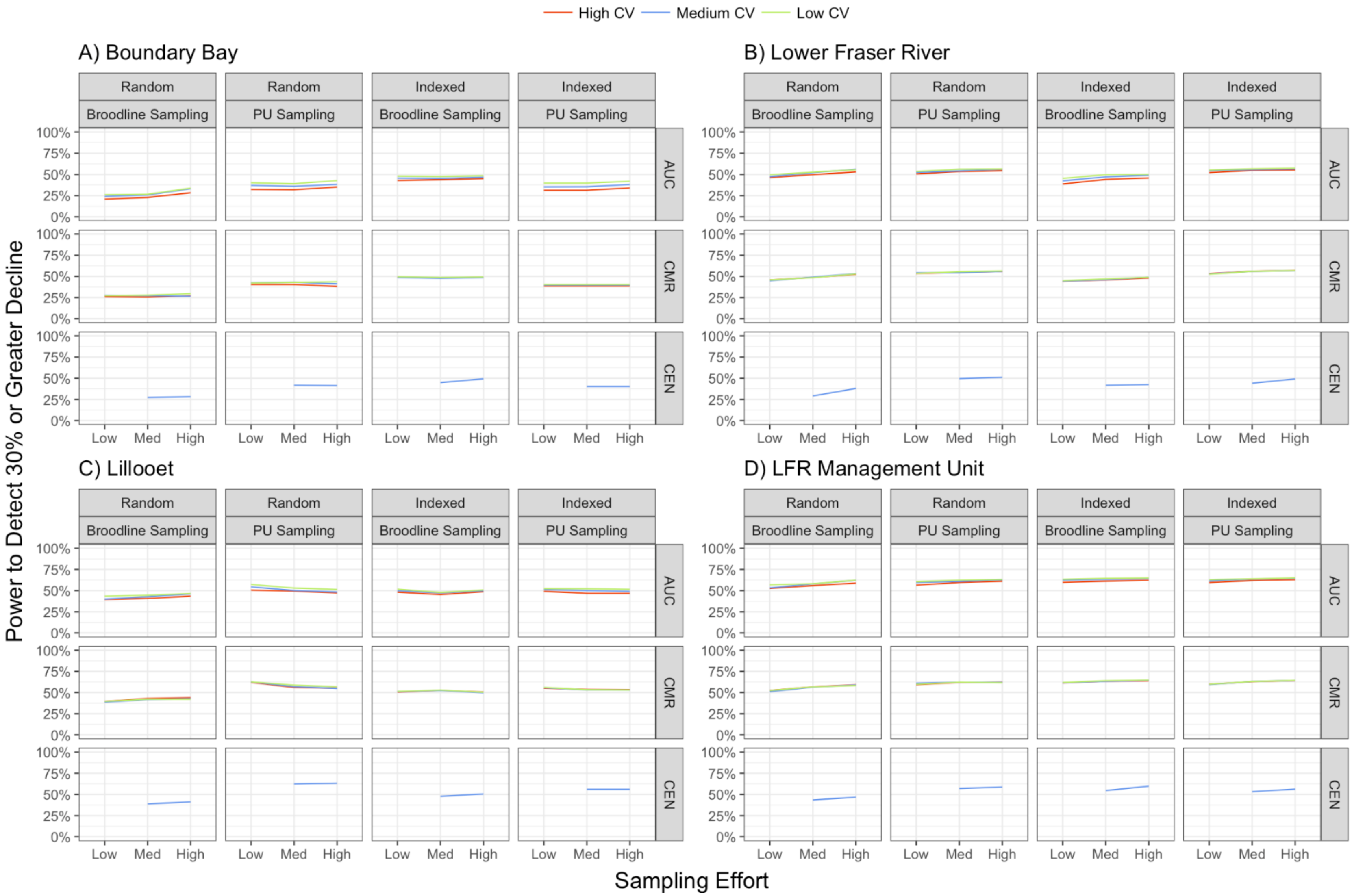

Figure 11. Differences in power to detect a 30% or larger decline within 10 years under a true decline of 90% within the same period for different precision and effort (see Survey Effort for effort and precision description).

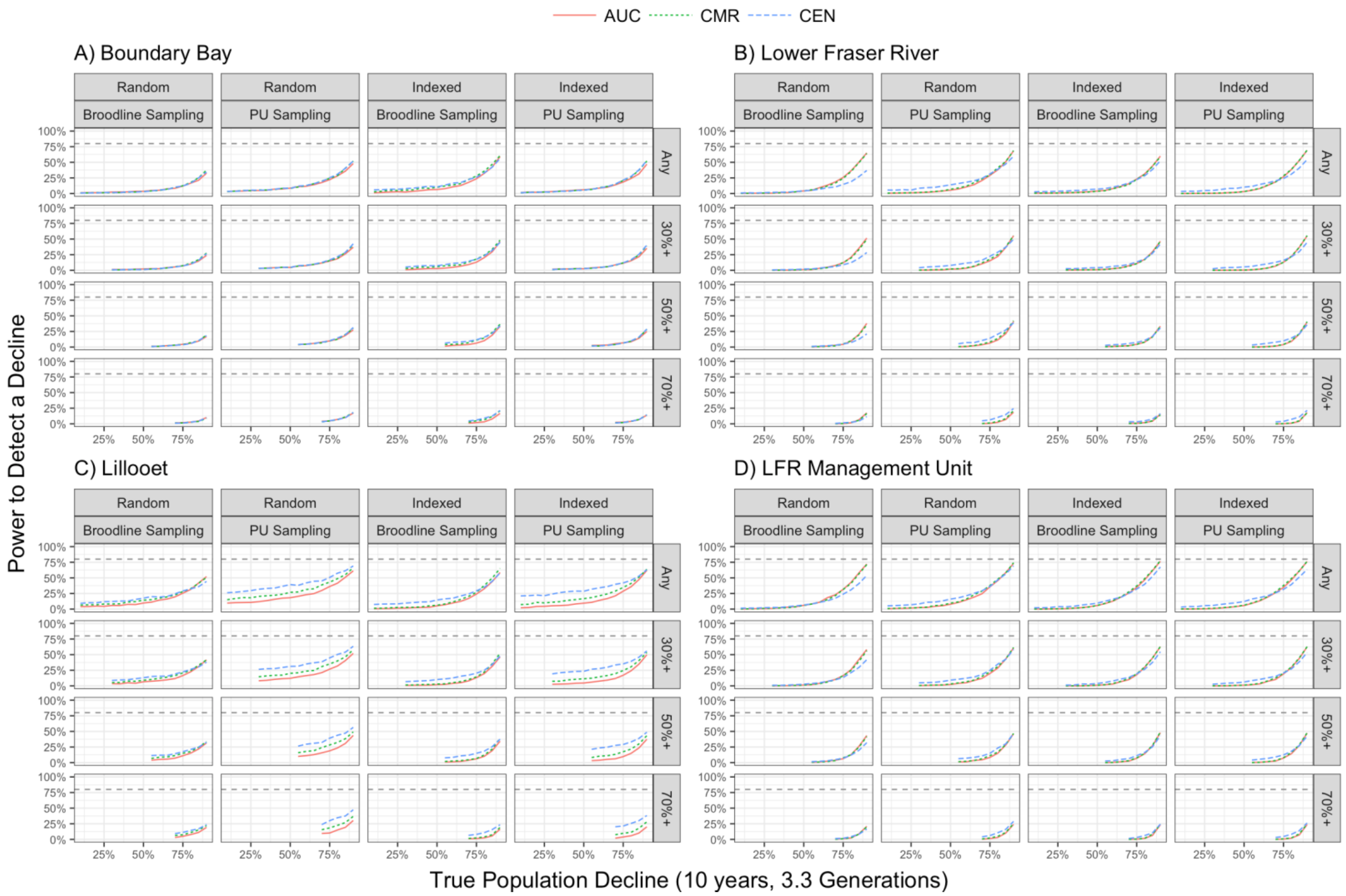

Figure 12. Power to detect an aggregate trend over 10 years by CU using three different assessment methods for A) Boundary Bay, B) Lower Fraser River and C) Lillooet Conservation Units and D) the Lower Fraser Management Unit. Horizontal dashed line indicates 80% power. Each assessment method used medium effort and precision scenarios. Panel columns indicate Management scale, while rows indicate decline hypotheses being tested. Strict hypothesis tests were employed.

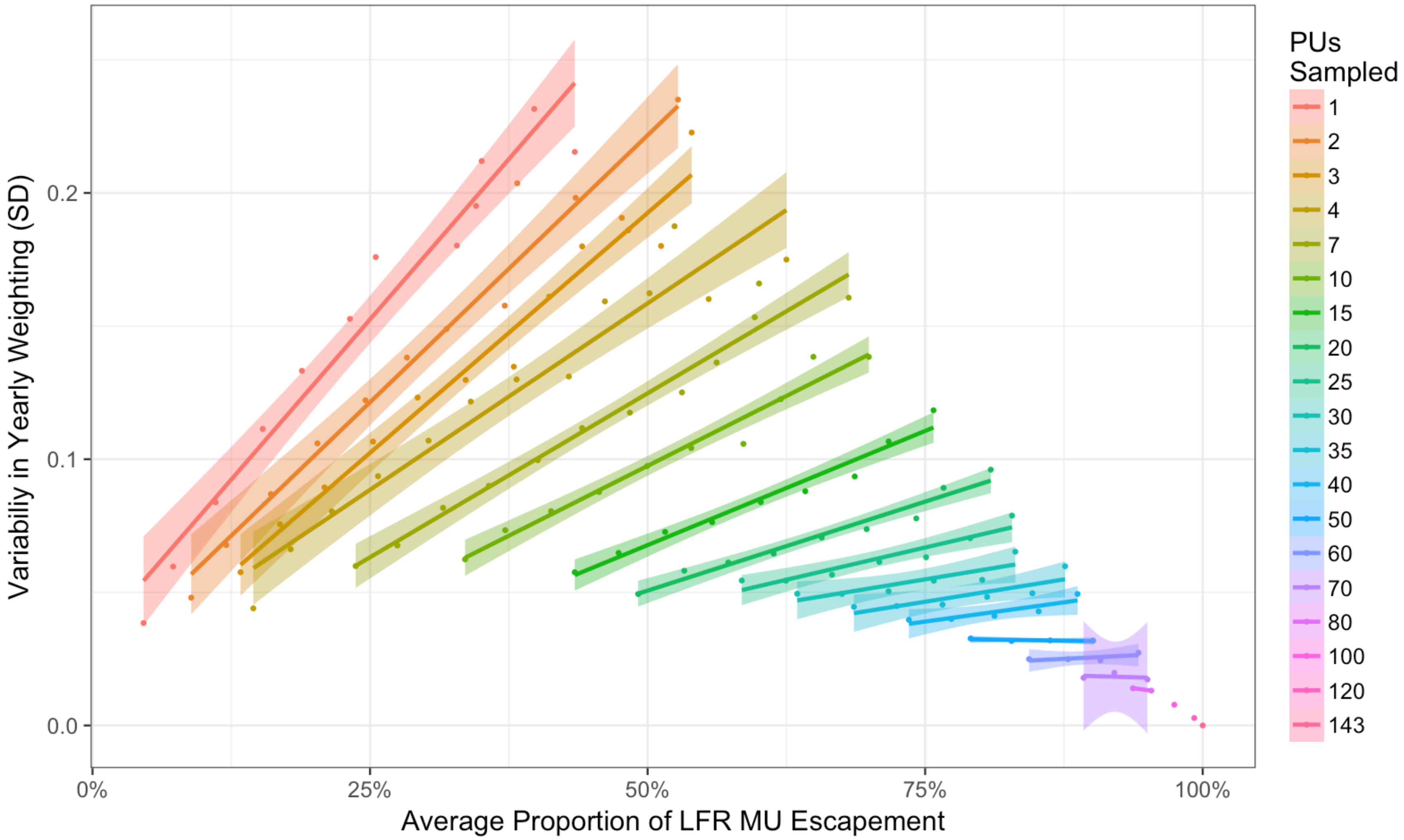

Figure 13. Relationship between yearly weighting variability and average PU productivity over 10 years for differing number of PUs sampled each year. Shading indicates 95% confidence region for each regression line.

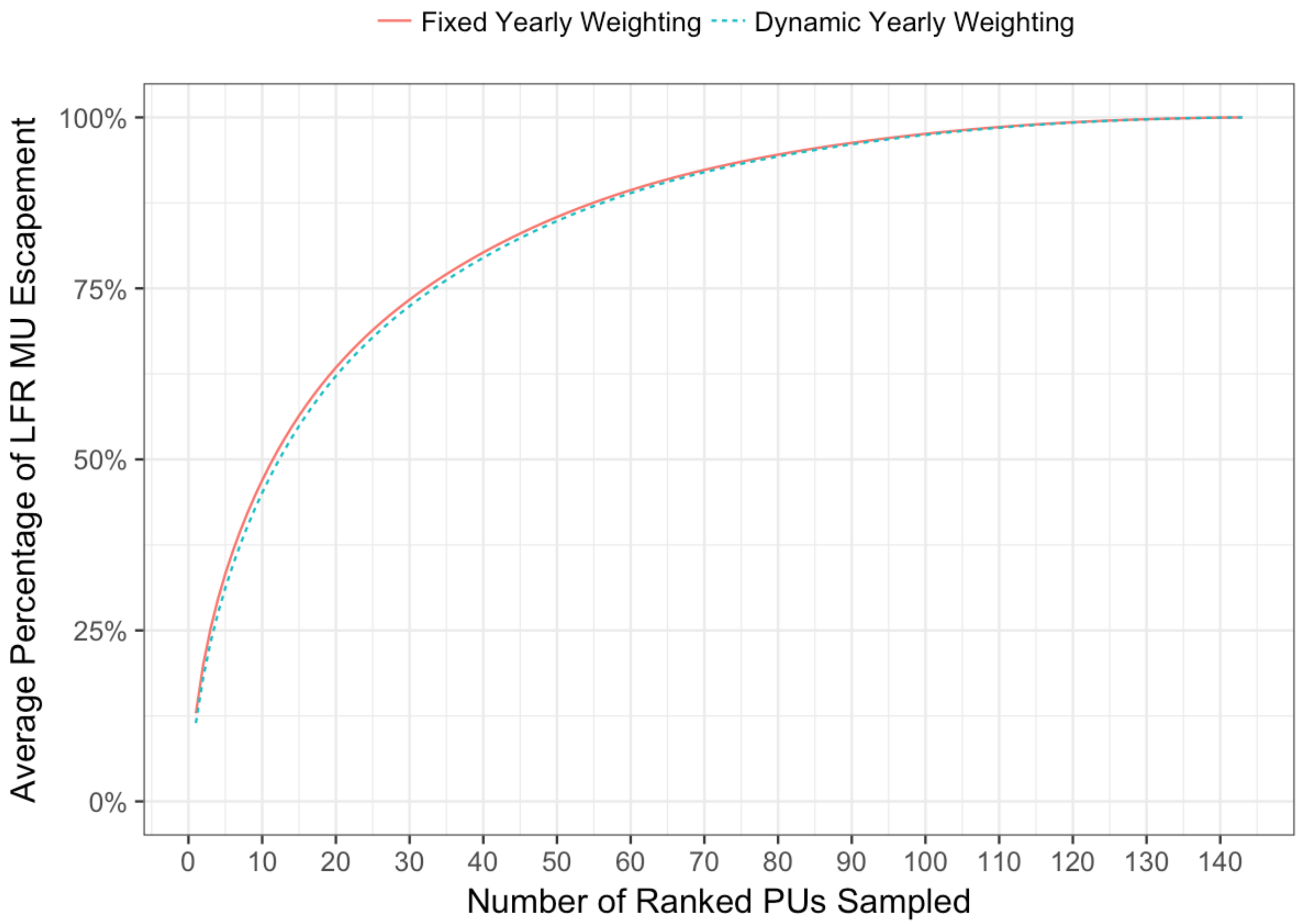

Figure 14. Potential bias in a fixed weighting scheme (i.e., identical weightings used each year) was investigated by comparing the average percentage of the LFR MU escapement described in a fixed weighting scheme as compared to the true average represented (dynamic yearly weighting). Averages were determined across differing number of PUs across 2,500 simulations.

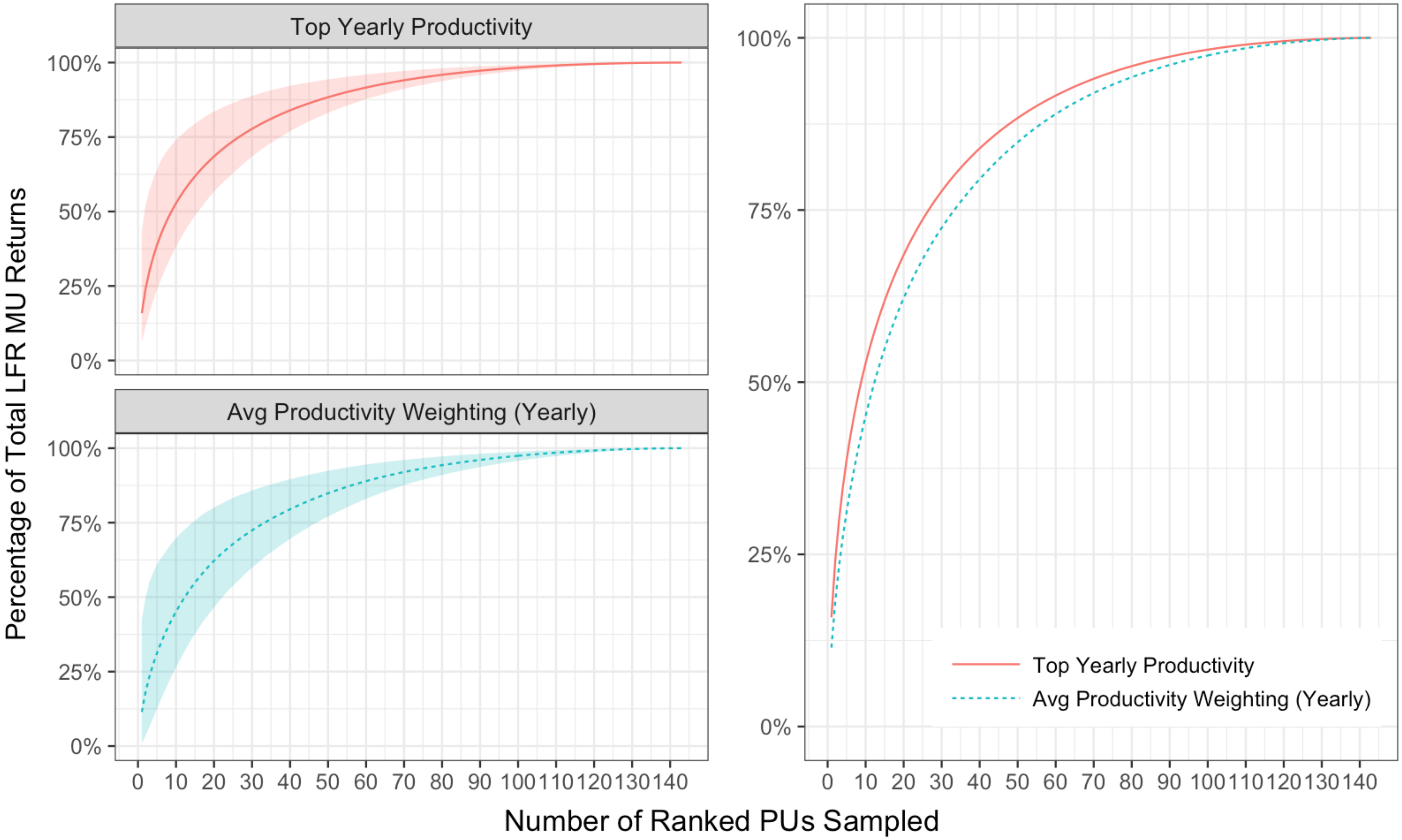

Figure 15. Proportion of the total LFR MU escapement represented by the inclusion of PUs from most productive to least productive. Two weighting schemes were considered, one that ranked PUs each year (left top panel) and a second that based the ranking on average PU productivity (left bottom panel). Right panel directly compares the average percentage described by each approach. Colour shading indicates the 2.5% and 97.5% percentiles from 2,500 simulations.

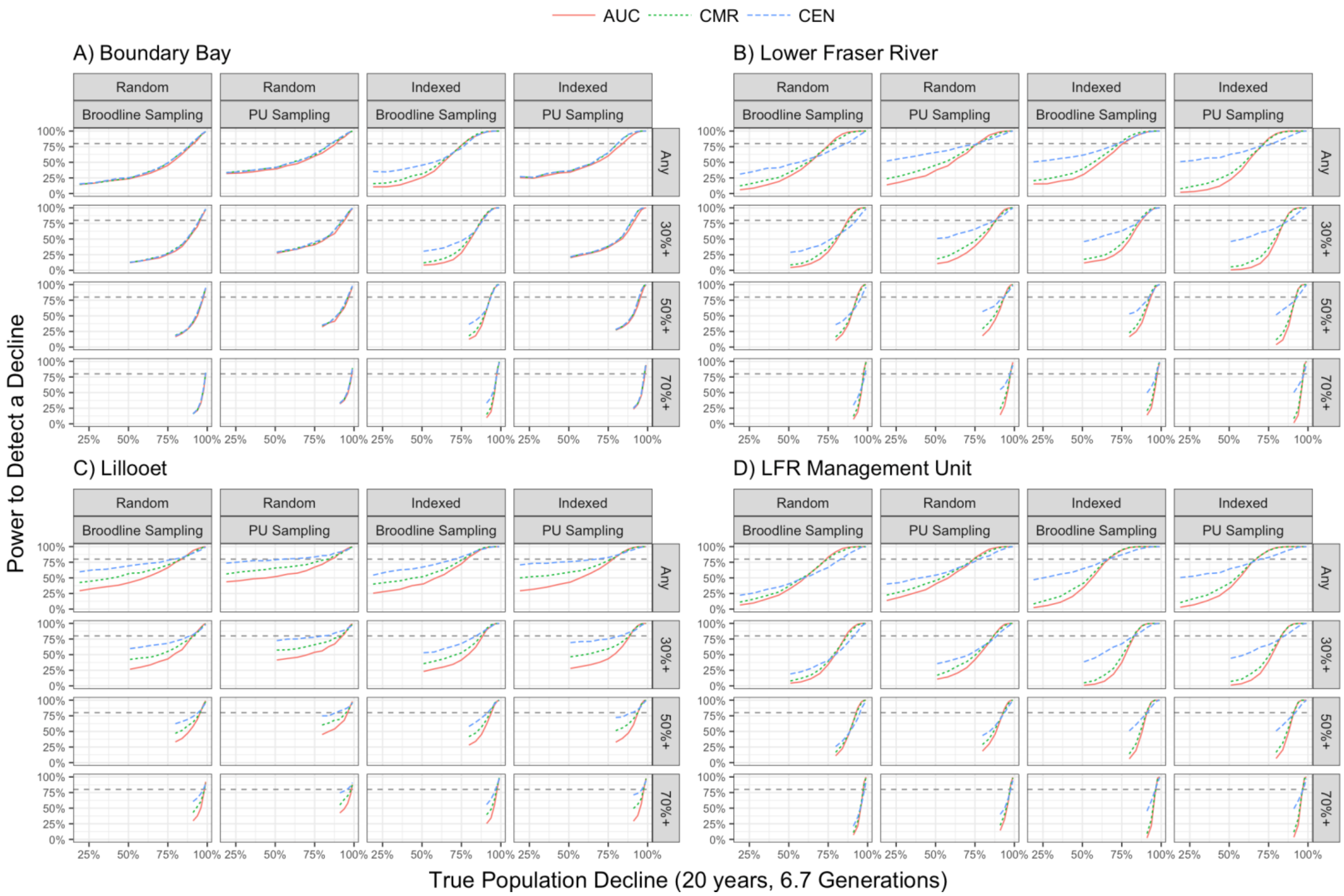

Figure 16. Comparison of the power to detect an aggregate trend over 20 years using three different assessment methods for A) Boundary Bay, B) Lower Fraser River and C) Lillooet Conservation Units and D) the Lower Fraser Management Unit. Horizontal dashed line indicates 80% power. Each assessment method used medium effort and precision scenarios. Panel columns indicate Management scale, while rows indicate decline hypotheses being tested. Strict hypothesis tests were employed.

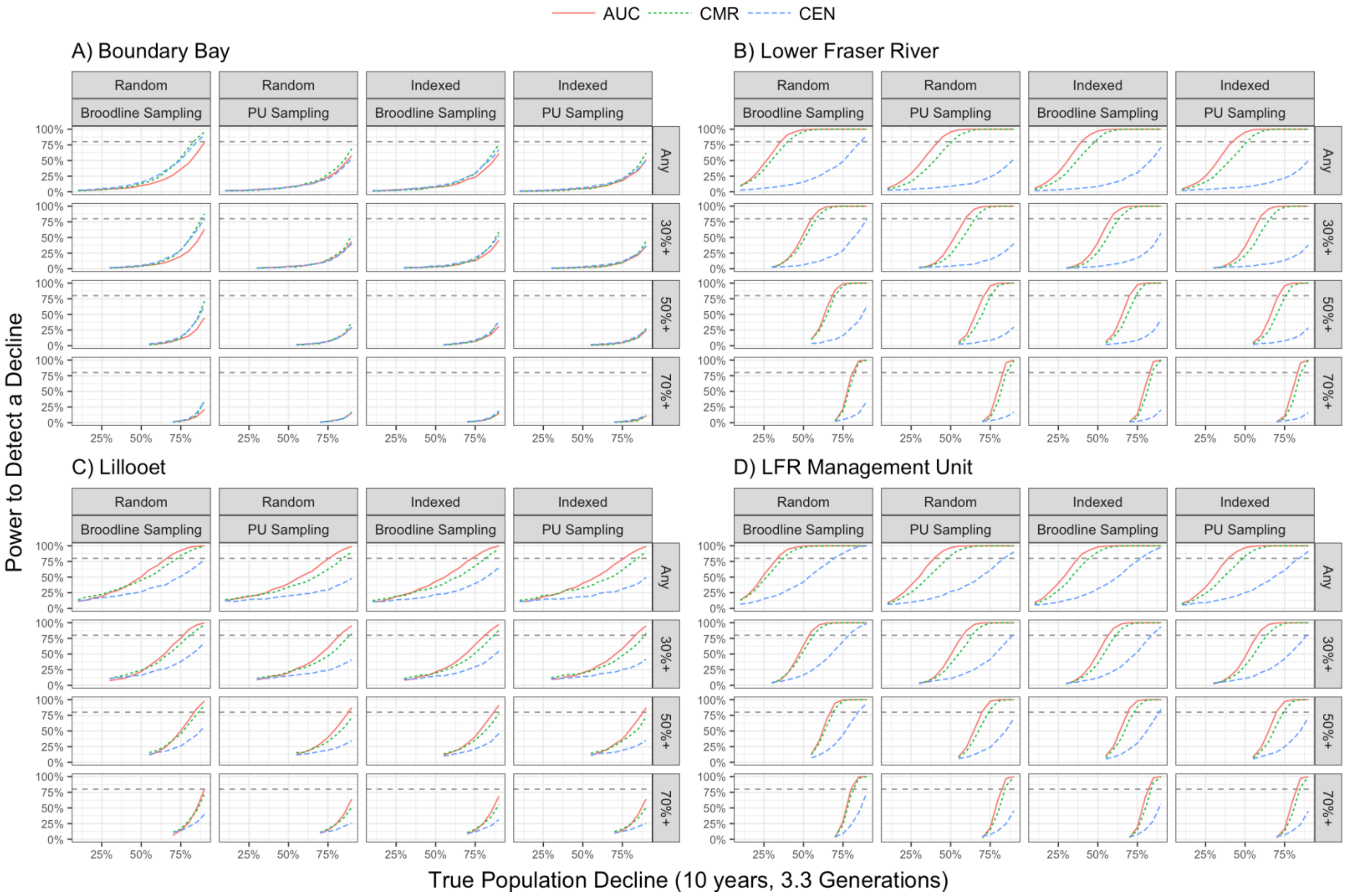

Figure 17. Comparison of the power to detect the average PU trend over 10 years using three different assessment methods for A) Boundary Bay, B) Lower Fraser River and C) Lillooet Conservation Units and D) the Lower Fraser Management Unit. Horizontal dashed line indicates 80% power. Each assessment method used medium effort and precision scenarios.

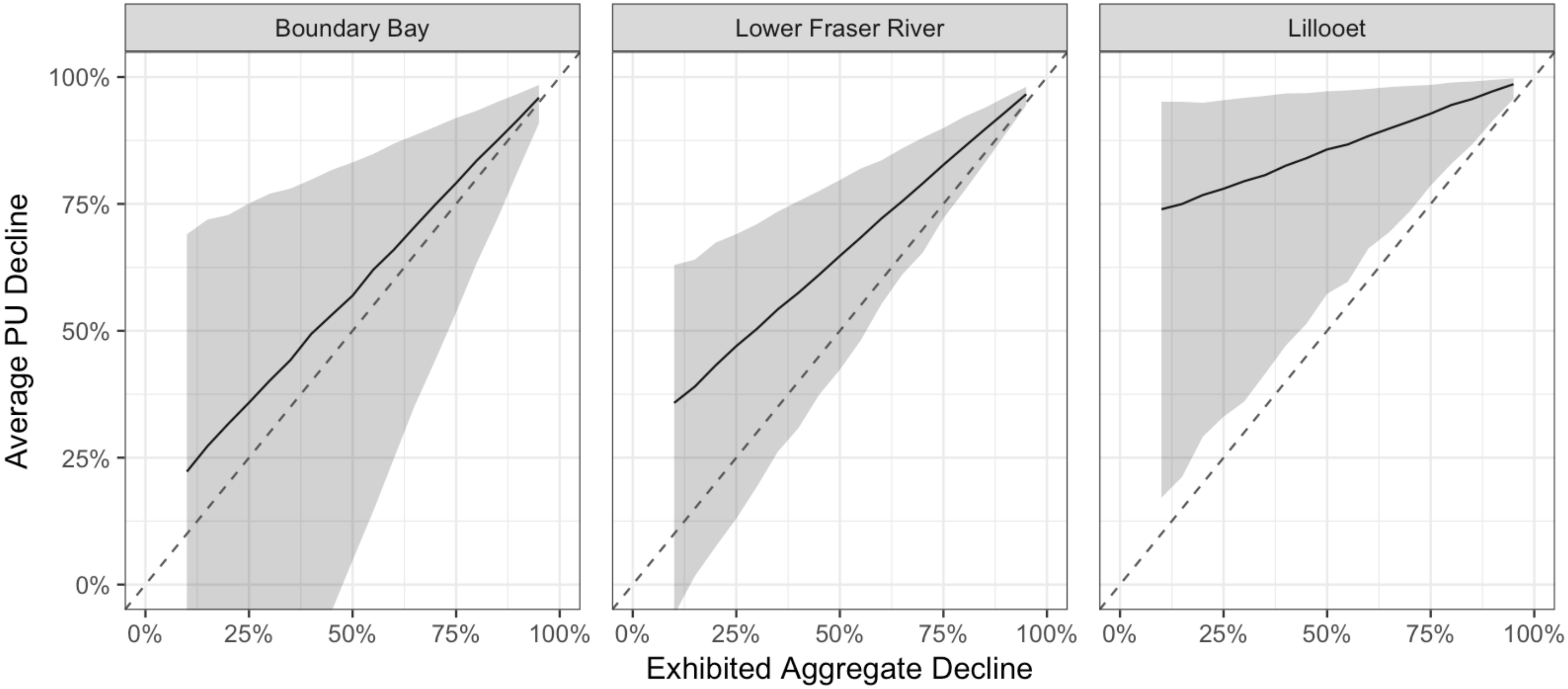

Figure 18. Distribution of average PU decline as a function of aggregate CU decline. Solid line indicates the average PU decline for a given aggregate decline, while the grey band indicates the interquartile range between the 2.5% and 97.5% percentiles in PU declines observed over 2,500 simulations. The dashed line indicates a 1:1 relationship.

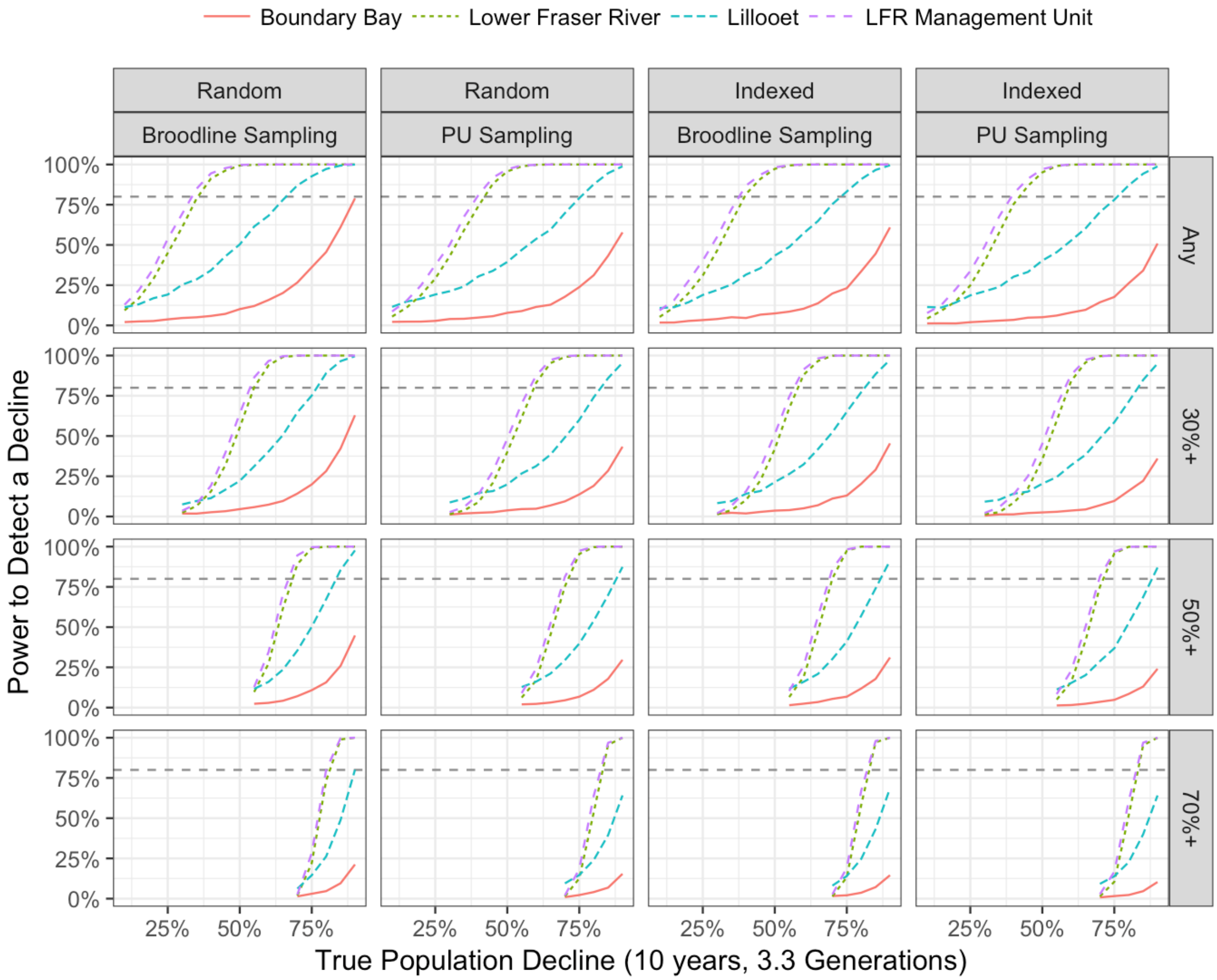

Figure 19. Comparison of power for detecting PU trends at different management scales. Power curves were computed under the AUC assessment method using the medium effort and medium precision scenarios. Panel columns indicate Management scale, while rows indicate decline hypotheses being tested. Strict hypothesis tests were employed.

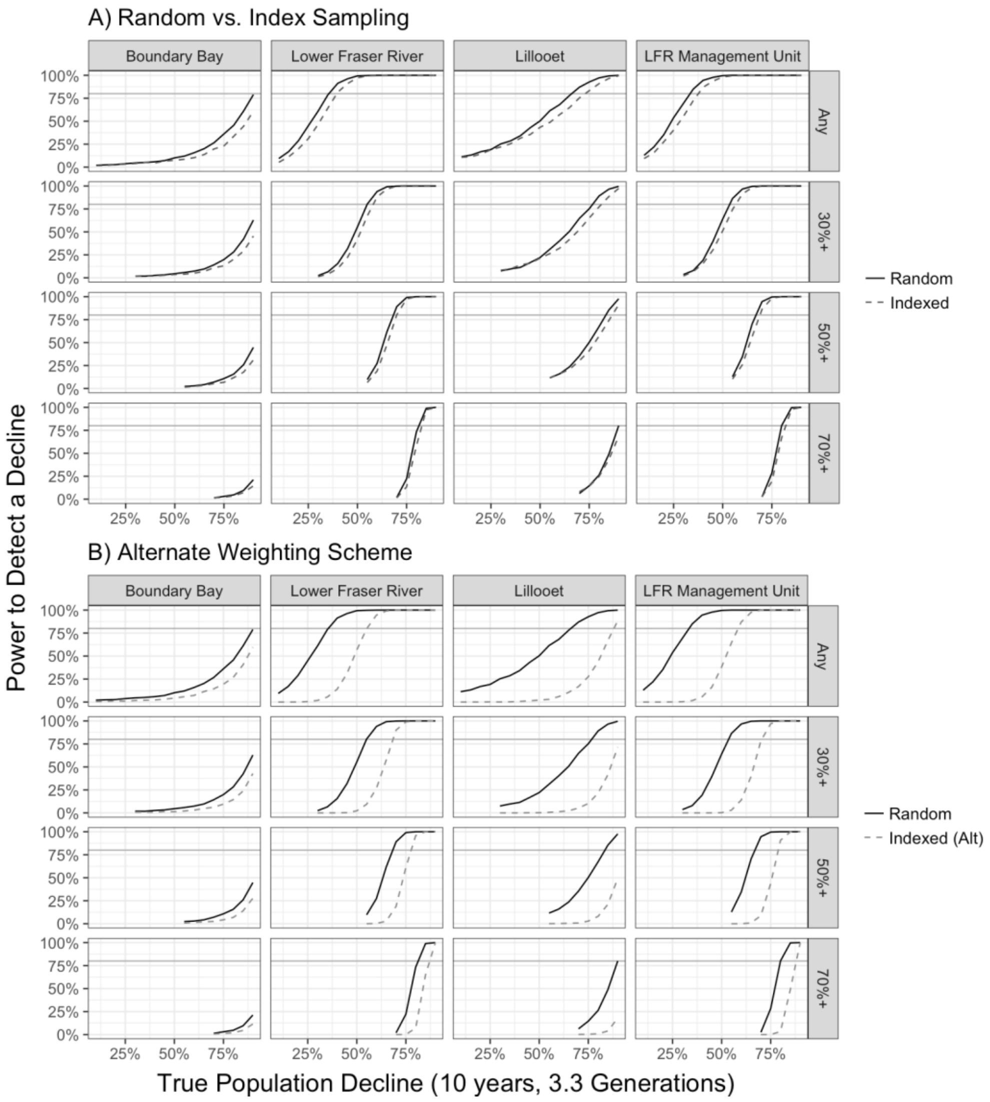

Figure 20. Comparison of A) random sampling versus index sampling for monitoring where index weighting was chosen prior to study period and B) after the trend had been applied. Comparison is based on using the AUC assessment method on randomly sampling broodlines within a CU under the medium CV and effort scenarios.

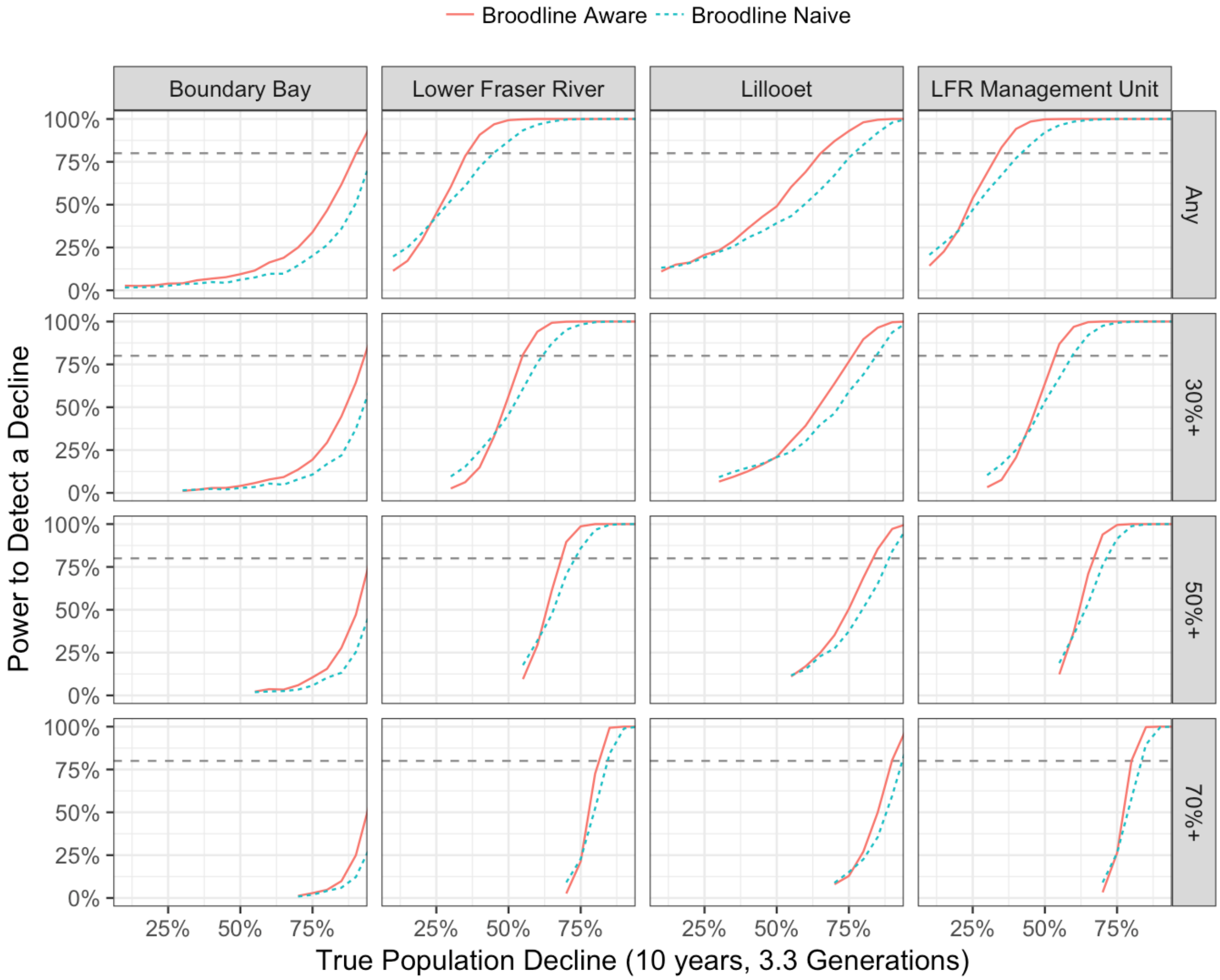

Figure 21. Comparisons of broodline aware and broodline naïve approaches to detecting average PU trend and B) aggregate trends. Power curves are for the AUC assessment method under medium effort and precision scenarios and using the strict statistical test for decline hypotheses. Panel columns indicate Management scale, while rows indicate decline hypotheses being tested. Strict hypothesis tests were employed.

APPENDIX A PARAMETER VALUES

Table A1. Simulator parameter values.

Component	Parameter	Conservation Unit BB	 LFR	 LILL	Description
$\bar{x}_j$	$\mu_{\bar{x}}$	5.38	5.38	5.81	Average site-specific log escapement
	$\sigma_{\bar{x}}$	1.44	1.44	1.44	Site-to-site variability in average abundance within a region.
$\eta_{B_t,j}$	$\beta_{A,0}$	-0.26	-0.26	-0.26	Brood A intercept
	$\beta_{A,1}$	0.04	0.04	0.04	Brood A slope for relationship to site-specific average abundance
	$\beta_{B,0}$	0.24	0.24	0.48	Brood B intercept
	$\beta_{B,1}$	-0.22	-0.22	-0.22	Brood B slope for relationship with Brood A effect.
	$\beta_{B,2}$	-0.23	-0.23	-0.11	Brood B interaction between site-specific average abundance and the Brood A effect.
	$\beta_{C,0}$	-0.17	-0.17	-0.41	Brood C intercept
	$\beta_{C,1}$	-0.57	-0.57	-0.57	Brood C slope for relationship with Brood A effect.
	$\beta_{C,2}$	-0.26	-0.26	-1.57	Brood C interaction between site-specific average abundance and the Brood A effect.
	σ_{η}	0.18	0.18	0.18	Degree of variability for residual brood effect error.
ω_t	σ_{ω}	0.55	0.55	0.55	Degree of variability in year-to-year in error shared within a region.
	θ_1	0.85	0.85	0.85	Lag-1 coefficient in the moving-average error indicating the degree regional errors are shared between years.
$\epsilon_{t,j}$	σ_{ϵ}	0.86	0.86	0.86	Degree of variability for residual site by year error within a region.
r_j	μ_r	variable	variable	variable	Average site-specific population trend over a 10-year period.
	σ_r	0.12	0.12	0.12	Variability in the site-specific trend.

Table A2. Estimated average PU-specific log abundance $(\bar{x}_j)$ used in the data simulator..

POPID (PU)	CU	Effect
564	LFR	-2.48
1925	LFR	-1.47
2436	LFR	-0.62
7472	LFR	-0.29
44644	LFR	-2.11
46035	LFR	0.10
46079	LFR	-1.12
46968	LFR	1.18
46977	LFR	1.10
46992	LFR	-0.11
46996	LFR	-2.09
47005	LFR	-0.10
47022	LFR	-0.69
47044	LFR	0.75
47058	LFR	1.17
47067	LFR	-0.14
47097	LFR	1.75
47555	LFR	0.48
47901	LFR	-1.81
47908	LFR	2.30
47923	LFR	0.06
47931	LFR	-0.47
47946	LFR	-0.48
47955	LFR	0.90
47961	LFR	0.85
47966	LFR	2.42
47976	LFR	0.81
47988	LFR	0.93
47998	LFR	0.16
48010	LFR	-0.24
48021	LFR	-0.73
46084	LILL	-1.28
46094	LILL	2.40
46099	LILL	2.11
46103	LILL	1.10
46108	LILL	-0.62
46113	LILL	-1.46
46123	LILL	-1.63
46153	LILL	1.08
69298	LILL	-1.70

APPENDIX B ESCAPEMENT DATA

Table B1. Boundary Bay Escapement meta data summary. TribDeme refers to the common name of the system, Affiliation references the agency responsible for the estimate, First and Last Dates are the first and last dates a survey was attempted, Interval (days) refers to the number of days between surveys, Total Surveys refers to the total surveys attempted in each year, Peak Data and Count refer to the date the peak escapement was observed and what it was observed as, Expansion refers to the ratio of peak count to final estimate, Final estimate is the best estimate of escapement, if possible, Type refers to how the Final escapement estimate was generated.

			Survey Information				**Peak**			**Escapement**	
TribDeme	**Affiliation**	**Year**	**First Date**	**Last Date**	**Interval (days)**	**Total surveys**	**Date**	**Count**	**Expansion**	**Final**	**Type**
Campbell River	NuSEDS	1997								2300	Unknown
Campbell River	NuSEDS	2004	17-Oct-04	4-Dec-04		5				1379	AUC
Little Campbell R	DFO	2004	17-Oct-04	2-Dec-04	7	5	22-Nov-04	209	3.0	625	AUC
Murray Cr	NuSEDS	1997	3-Dec-97	29-Jan-98		3				116	Unk.
Nicomekl River	NuSEDS	1997								1650	Unk.
Serpentine R	NuSEDS	1997								1500	Unk.
Serpentine R	DFO	2004	22-Oct-04	13-Dec-04	15	6	8-Nov-04	392	4.6	1799	AUC

Table B2. Lower Fraser River CU Escapement meta data summary. TribDeme refers to the common name of the system, Affiliation references the agency responsible for the estimate, First and Last Dates are the first and last dates a survey was attempted, Interval (days) refers to the number of days between surveys, Total Surveys refers to the total surveys attempted in each year, Peak Data and Count refer to the date the peak escapement was observed and what it was observed as, Expansion refers to the ratio of peak count to final estimate, Final estimate is the best estimate of escapement, if possible, Type refers to how the Final escapement estimate was generated.

			Survey Information				**Peak**			**Escapement**	
TribDeme	**Affiliation**	**Year**	**First Date**	**Last Date**	**Interval (days)**	**Total surveys**	**Date**	**Count**	**Expansion**	**Final**	**Type**
14 Mile Cr	nuSEDS	1997								190	Unk.
14 Mile Cr	nuSEDS	1998								140	Unk.
14 Mile Cr	nuSEDS	1999	14-Oct-99	24-Jan-00		8				640	Unk.
14 Mile Cr	nuSEDS	2000								1502	Unk.
14 Mile Cr	SEP	2004	4-Nov-04	29-Dec-04	7	9	25-Nov-04	213	4.1	868	AUC
14 Mile Cr	SEP	2005	25-Oct-05	10-Jan-06	2	13	21-Nov-05	54	6.2	333	AUC
14 Mile Cr	SEP	2006	12-Oct-06	27-Dec-06	14	11	23-Nov-06	68	3.4	231	AUC
14 Mile Cr	SEP	2007	25-Oct-07	9-Jan-08	6	12	6-Dec-07	155	3.9	597	AUC
14 Mile Cr	SEP	2008	16-Oct-08	29-Dec-08	14	10	5-Nov-08	32	3.4	109	AUC
14 Mile Cr	SEP	2009	20-Oct-09	29-Dec-09	7	11	23-Nov-09	99	4.7	467	AUC
14 Mile Cr	SEP	2010	21-Oct-10	29-Dec-10	6	10	30-Nov-10	215	4.6	996	AUC
14 Mile Cr	SEP	2011	20-Oct-11	29-Dec-11	4	11	30-Nov-11	139	4.5	631	AUC
14 Mile Cr	SEP	2012	25-Oct-12	15-Jan-13	7	13	6-Nov-12	165	5.6	924	AUC
14 Mile Cr	SEP	2013	2-Oct-13	23-Jan-14	5	13	3-Dec-13	94	5.2	488	AUC
15 Mile Cr	nuSEDS	1997								35	Unk.
15 Mile Cr	nuSEDS	1998								75	Unk.
15 Mile Cr	DFO	2004	7-Oct-04	17-Dec-04	11	9	30-Nov-04	17	2.0	35	AUC
Angel Wing Channel	nuSEDS	1998								240	Unk.
Atchelitz Creek	nuSEDS	1997								N/A	N/A
Barnes Cr	nuSEDS	2001	13-Nov-01	22-Jan-02		9				220	AUC
Barnes Cr	nuSEDS	2002	15-Oct-02	22-Jan-02		9				233	AUC
Barnes Cr	DFO	2004	6-Oct-04	3-Feb-05	14	16	3-Dec-04	27	5.3	142	AUC
Barnes Cr	DFO	2005	12-Oct-05	3-Jan-06	15	7	23-Dec-05	34	1.8	62	AUC

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Barnes Cr	DFO	2006	29-Sep-06	10-Jan-07	41	10	20-Nov-06	22	5.4	119	AUC
Barnes Cr	DFO	2008	6-Oct-08	29-Jan-09	8	14	10-Dec-08	34	3.3	113	AUC
Barnes Cr	DFO	2009	16-Oct-09	22-Jan-10	27	13	30-Nov-09	28	4.2	119	AUC
Barnes Cr	DFO	2010	6-Oct-10	3-Feb-11	7	17	15-Dec-10	49	3.6	178	AUC
Barnes Cr	DFO	2011	11-Oct-11	6-Feb-12	7	16	1-Dec-11	65	5.2	340	AUC
Barnes Cr	DFO	2012	10-Oct-12	30-Jan-13	6	16	20-Nov-12	17	5.0	85	AUC
Barnes Cr	DFO	2013	3-Oct-13	7-Feb-14	7	17	4-Dec-13	54	6.2	333	AUC
Barnes Cr	DFO	2014	10-Oct-14	19-Jan-15	6	15	10-Dec-14	57	3.2	185	AUC
Barnes Cr	DFO	2015	7-Oct-15	29-Jan-16	7	15	25-Nov-15	13	5.2	67	AUC
Barrett Creek	nuSEDS	1997								30	Unk.
Barrett Creek	nuSEDS	1998								60	Unk.
Blaney Cr	nuSEDS	1997	11-Nov-97	11-Nov-97						0	N/A
Blaney Cr	nuSEDS	1998								353	Unk.
Blaney Cr	nuSEDS	1999	15-Oct-99	10-Jan-00		5				71	Unk.
Blaney Cr	nuSEDS	2000								34	Unk.
Blaney Cr	nuSEDS	2001	23-Oct-01	23-Jan-02		9				36	AUC
Blaney Cr	nuSEDS	2002	1-Oct-02	14-Jan-03		6				150	AUC
Blaney Cr	DFO	2004	30-Sep-04	28-Dec-04	6	10	17-Nov-04	66	3.6	237	AUC
Blaney Cr	nuSEDS	2005	8-Nov-05	11-Jan-06		1				211	AUC
Blaney Cr	DFO	2008	2-Oct-08	15-Jan-09	6	14	4-Dec-08	15	2.1	31	AUC
Blaney Cr	DFO	2009	13-Nov-09	6-Jan-10	7	7	13-Nov-09	3	3.4	10	AUC
Blaney Cr	DFO	2010	20-Oct-10	20-Jan-11	7	12	17-Nov-10	86	4.5	386	AUC
Blaney Cr	DFO	2011	10-Oct-11	27-Jan-12	7	14	8-Dec-11	32	4.0	128	AUC
Blaney Cr	DFO	2012	9-Oct-12	30-Jan-13	9	15	14-Dec-12	52	6.0	310	AUC
Blaney Cr	DFO	2013	4-Oct-13	6-Feb-14	21	15	30-Dec-13	260	5.5	1439	AUC
Blaney Cr	DFO	2014	15-Oct-14	23-Jan-15	5	15	1-Dec-14	123	4.2	512	AUC
Blaney Cr	DFO	2015	6-Oct-15	25-Jan-16	9	14	21-Dec-15	25	4.4	110	AUC
Borden Creek	nuSEDS	1997								140	Unk.
Borden Creek	nuSEDS	1998								70	Unk.

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Brunette River	nuSEDS	1997								125	Unk.
Bulbeard Channel	nuSEDS	1998								100	Unk.
Byrne Cr	Byrne Creek Streamkeepers	2004								24	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2005								26	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2006								8	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2007								7	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2008								8	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2009								4	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2010								8	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2011								21	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2012								7	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2013								26	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2014								10	Carcass only
Byrne Cr	Byrne Creek Streamkeepers	2015								6	Carcass only
Calkins Creek	nuSEDS	1997								N/A	N/A
Centennial Channel	nuSEDS	1997								70	Unk.
Centennial Channel	nuSEDS	1998								100	Unk.

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Centre Channel	nuSEDS	1997								N/A	N/A
Centre Channel	nuSEDS	1998								N/A	N/A
Centre Creek	nuSEDS	1997								N/A	N/A
Chilliwack River	nuSEDS	1997								N/A	N/A
Chilliwack River	nuSEDS	1998								N/A	N/A
Chilliwack/Vedder River	nuSEDS	1997								N/A	N/A
Chilliwack/Vedder River	nuSEDS	1997								6110	Unk.
Chilliwack/Vedder River	nuSEDS	1998								5965	Unk.
Chilqua Cr	nuSEDS	1999								N/A	N/A
Chilqua Cr	nuSEDS	2001	13-Nov-01	22-Jan-02		8				300	AUC
Chilqua Cr	nuSEDS	2002	1-Oct-02	31-Jan-03		6				186	AUC
Chilqua Cr	DFO	2004	20-Oct-04	10-Feb-05	8	16	14-Dec-04	172	4.5	766	AUC
Chilqua Cr	DFO	2005	5-Dec-05	11-Jan-06	12	4	30-Dec-05	23	3.6	83	PCExp
Chilqua Cr	DFO	2006	2-Oct-06	1-Feb-07	32	10	5-Jan-07	25	6.9	172	AUC
Chilqua Cr	DFO	2008	6-Oct-08	29-Jan-09	8	13	22-Jan-09	27	2.1	56	AUC
Chilqua Cr	DFO	2009	3-Dec-09	3-Dec-09	n.a.	1	n.a.	0		0	NO
Chilqua Cr	DFO	2010	6-Oct-10	26-Jan-11	7	16	15-Dec-10	21	2.8	59	AUC
Chilqua Cr	DFO	2011	2-Nov-11	31-Jan-12	7	13	6-Jan-12	3	3.8	11	PCExp
Chilqua Cr	DFO	2012	6-Oct-12	8-Feb-13	4	19	18-Jan-13	159	1.9	309	AUC
Chilqua Cr	DFO	2013	3-Oct-13	7-Feb-14	27	15	10-Jan-14	61	2.3	143	AUC
Chilqua Cr	DFO	2014	10-Oct-14	19-Jan-15	6	15	24-Dec-14	23	3.0	70	AUC
Chilqua Cr	DFO	2015	7-Oct-15	29-Jan-16	7	15	24-Dec-15	7	4.6	32	AUC
Coghlan Cr	nuSEDS	1997								N/A	N/A
Coghlan Cr	nuSEDS	1999								N/A	Unk.
Coghlan Cr	nuSEDS	2000	18-Oct-00	22-Jan-01		11				2192	AUC
Coghlan Cr	nuSEDS	2001	25-Oct-01	21-Jan-02		11				4222	AUC

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Coghlan Cr	nuSEDS	2002	30-Oct-02	21-Jan-03		7				1682	AUC
Coghlan Cr	DFO	2004	25-Oct-04	1-Feb-05	15	11	9-Nov-04	312	4.1	1279	AUC
Coghlan Cr	DFO	2005	21-Oct-05	11-Jan-06	5	11	16-Nov-05	63	3.0	188	AUC
Coghlan Cr	DFO	2006	25-Oct-06	12-Jan-07	23	9	17-Nov-06	48	3.6	172	AUC
Coghlan Cr	DFO	2008	27-Oct-08	30-Jan-09	15	10	1-Dec-08	50	3.6	178	AUC
Coghlan Cr	DFO	2009	9-Dec-09	9-Dec-09	n.a.	1	9-Dec-09	27	4.1	111	PCExp
Coquitlam River	nuSEDS	1997								1000	Unk.
Coquitlam River	BCHydro	2002								2648	AUC
Coquitlam River	BCHydro	2003								1562	AUC
Coquitlam River	BCHydro	2004								2562	AUC
Coquitlam River	BCHydro	2005								1334	AUC
Coquitlam River	BCHydro	2006								939	AUC
Coquitlam River	BCHydro	2007								2401	AUC
Coquitlam River	BCHydro	2008								878	AUC
Coquitlam River	BCHydro	2009								3175	AUC
Coquitlam River	BCHydro	2010								12338	AUC
Coquitlam River	BCHydro	2011								8428	AUC
Depot Cr	nuSEDS	1997								75	Unk.
Depot Cr	nuSEDS	1998								105	Unk.
Depot Cr	SEP	2004	25-Oct-04	11-Dec-04	2	9	17-Nov-04	119	3.2	378	AUC
Depot Cr	SEP	2005	21-Oct-05	4-Dec-05	3	8	2-Nov-05	27	3.6	98	AUC
Depot Cr	SEP	2006	20-Oct-06	23-Nov-06	6	6	9-Nov-06	18	2.2	40	AUC
Depot Cr	SEP	2007	17-Oct-07	31-Dec-07	8	11	20-Nov-07	64	4.7	304	AUC
Depot Cr	SEP	2008	17-Oct-08	16-Dec-08	5	9	14-Nov-08	9	3.5	32	AUC
Depot Cr	SEP	2009	20-Oct-09	30-Nov-09	5	6	10-Nov-09	47	4.1	191	AUC
Depot Cr	SEP	2010	4-Oct-10	20-Dec-10	16	8	8-Nov-10	132	3.6	479	AUC
Depot Cr	SEP	2011	20-Oct-11	15-Dec-11	5	9	30-Nov-11	93	2.8	263	AUC
Depot Cr	SEP	2012	19-Oct-12	6-Dec-12	5	7	7-Nov-12	54	3.8	206	AUC
Depot Cr	SEP	2013	20-Oct-13	13-Dec-13	5	4	15-Nov-13	46	4.1	188	AUC

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Downes Cr	nuSEDS	1997								N/A	N/A
Dunlop Cr	DFO	2011	8-Dec-11	27-Jan-12	18	10	19-Dec-11	85	2.3	199	AUC
Dunlop Cr	DFO	2012	28-Nov-12	30-Jan-13	14	9	10-Dec-12	56	3.0	171	AUC
Dunville Creek	nuSEDS	1997								N/A	N/A
Elk Cr	nuSEDS	1997								N/A	N/A
Elk Cr	SEP	2006	1-Dec-06	8-Jan-07	5	7	21-Dec-06	60	2.2	134	AUC
Elk Cr	SEP	2011	18-Nov-11	25-Nov-11	7	2	25-Nov-11	30	3.8	115	PCExp
Elk Cr	SEP	2012	14-Nov-12	9-Jan-13	5	4	14-Dec-12	205	7.7	1579	AUC
Foley Creek	nuSEDS	1997								70	Unk.
Foley Creek	nuSEDS	1998								90	Unk.
Foley Creek Side Channel	nuSEDS	1997								25	Unk.
Foley Creek Side Channel	nuSEDS	1998								10	Unk.
Forcite Side Channel	nuSEDS	1997								0	N/A
Forcite Side Channel	nuSEDS	1998								0	N/A
Giesbrecht Spawning Channel	nuSEDS	1997								5	Unk.
Hicks Cr	nuSEDS	1997	6-Dec-97	6-Dec-97		1				6	Unk.
Hicks Cr	nuSEDS	2001	30-Oct-01	26-Feb-02		16				5224	AUC
Hicks Cr	nuSEDS	2002	9-Oct-02	11-Feb-03		12				993	AUC
Hicks Cr	DFO	2004	8-Oct-04	10-Feb-05	7	18	21-Jan-05	261	6.6	1730	AUC
Hicks Cr	DFO	2005	25-Oct-05	19-Jan-06	9	12	29-Dec-05	326	2.3	738	AUC
Hicks Cr	DFO	2006	29-Sep-06	1-Feb-07	20	15	14-Dec-06	116	4.5	519	AUC
Hicks Cr	DFO	2008	3-Oct-08	29-Jan-09	6	18	10-Dec-08	161	4.7	750	AUC
Hicks Cr	DFO	2009	3-Nov-09	18-Jan-10	7	13	21-Dec-09	304	6.3	1909	AUC
Hicks Cr	DFO	2010	12-Oct-10	4-Feb-11	7	18	14-Dec-10	216	6.7	1441	AUC

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Hicks Cr	DFO	2011	5-Oct-11	30-Jan-12	9	17	29-Dec-11	248	4.3	1056	AUC
Hicks Cr	DFO	2012	5-Oct-12	7-Feb-13	7	18	21-Nov-12	434	5.8	2510	AUC
Hicks Cr	DFO	2013	2-Oct-13	3-Feb-14	7	16	19-Dec-13	577	6.5	3775	AUC
Hicks Cr	DFO	2014	9-Oct-14	29-Jan-15	7	16	12-Dec-14	190	5.7	1077	AUC
Hicks Cr	DFO	2015	2-Oct-15	27-Jan-16	7	16	10-Dec-15	147	4.8	704	AUC
Hope Slough	nuSEDS	1997								N/A	N/A
Hopedale Cr	nuSEDS	1997								0	N/A
Hopedale Cr	nuSEDS	1998								85	Unk.
Hopedale Cr	nuSEDS	2000								85	Unk.
Hopedale Slough	nuSEDS	1997								10	Unk.
Hopedale Slough	nuSEDS	1998								230	Unk.
Hopedale Slough	nuSEDS	1999	14-Oct-99	20-Jan-00		15				148	Unk.
Hopedale Slough	nuSEDS	2000	20-Oct-00	24-Jan-01		4				59	AUC
Hopedale Slough	nuSEDS	2001	23-Oct-01	30-Jan-02		9				259	AUC
Hopedale Slough	nuSEDS	2002	30-Sep-02	30-Jan-03		9				131	AUC
Hopedale Slough	DFO	2004	7-Oct-04	10-Feb-05	11	17	19-Jan-05	211	4.7	997	AUC
Hopedale Slough	DFO	2005	12-Oct-05	19-Jan-06	26	10	28-Dec-05	61	3.1	190	AUC
Hopedale Slough	DFO	2006	25-Sep-06	15-Jan-07	7	17	27-Dec-06	10	3.8	38	AUC
Hopedale Slough	DFO	2008	3-Oct-08	20-Jan-09	21	14	11-Dec-08	14	2.7	38	AUC
Hopedale Slough	DFO	2009	10-Nov-09	5-Feb-10	7	14	12-Jan-10	27	3.0	81	AUC
Hopedale Slough	DFO	2010	11-Oct-10	4-Feb-11	7	16	27-Dec-10	426	4.4	1885	AUC
Hopedale Slough	DFO	2011	12-Oct-11	23-Jan-12	7	15	20-Dec-11	129	4.5	585	AUC
Hopedale Slough	DFO	2012	15-Oct-12	29-Jan-13	7	15	9-Jan-13	69	1.3	91	AUC
Hopedale Slough	DFO	2013	7-Oct-13	13-Feb-14	21	17	3-Jan-14	274	4.9	1348	AUC
Hopedale Slough	DFO	2014	14-Oct-14	21-Jan-15	7	14	4-Dec-14	60	4.2	254	AUC
Hopedale Slough	DFO	2015	5-Oct-15	28-Jan-16	8	16	14-Dec-15	32	5.8	187	AUC
Hoy Creek	nuSEDS	1997								150	Unk.
Hyde Creek	nuSEDS	1997								75	Unk.
Intake Creek	nuSEDS	1997								130	Unk.

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Intake Creek	nuSEDS	1998								400	Unk.
Kanaka Cr	nuSEDS	1997				8				2495	Unk.
Kanaka Cr	nuSEDS	2001	9-Nov-01	21-Jan-02		7				1263	AUC
Kanaka Cr	nuSEDS	2002	8-Oct-02	13-Jan-03		10				2042	AUC
Kanaka Cr	DFO	2004	5-Oct-04	5-Jan-05	15	10	22-Dec-04	283	5.4	1529	AUC
Kanaka Cr	DFO	2005	15-Nov-05	19-Jan-06	14	5	8-Dec-05	93	5.5	512	AUC
Kanaka Cr	DFO	2006	27-Sep-06	12-Jan-07	10	6	28-Dec-06	10	3.6	36	PCExp
Kanaka Cr	DFO	2008	2-Oct-08	22-Jan-09	6	15	19-Nov-08	144	2.5	363	AUC
Kanaka Cr	DFO	2009	5-Nov-09	6-Jan-10	5	8	25-Nov-09	9	3.6	32	AUC
Kanaka Cr	DFO	2010	7-Oct-10	20-Jan-11	7	14	2-Dec-10	585	5.1	2967	AUC
Kanaka Cr	DFO	2011	10-Oct-11	27-Jan-12	7	19	29-Nov-11	515	3.8	1974	AUC
Kanaka Cr	DFO	2012	9-Oct-12	30-Jan-13	9	18	28-Nov-12	117	4.1	475	AUC
Kanaka Cr	DFO	2013	4-Oct-13	6-Feb-14	7	17	30-Dec-13	828	3.4	2808	AUC
Kanaka Cr	DFO	2014	15-Oct-14	23-Jan-15	13	14	8-Dec-14	279	5.3	1467	AUC
Kanaka Cr	DFO	2015	6-Oct-15	25-Jan-16	9	12	30-Dec-15	52	3.9	203	AUC
Lagace Cr	nuSEDS	1998								73	Unk.
Lagace Cr	nuSEDS	1999	13-Oct-99	6-Jan-00		8				66	Unk.
Lagace Cr	nuSEDS	2000								1899	Unk.
Little Tamihi Cr	nuSEDS	1997								N/A	N/A
Liumchen Cr	nuSEDS	1997								N/A	N/A
Lonzo Creek	nuSEDS	1997								N/A	N/A
Lorenzetta Cr	nuSEDS	1997	6-Dec-97	6-Dec-97		1				N/A	Unk.
Luckackuk Cr	nuSEDS	1997								N/A	N/A
Macintyre Cr	nuSEDS	2002	8-Oct-02	14-Jan-03		5				240	AUC
Macintyre Cr	nuSEDS	2004	30-Sep-03	12-Dec-03		6				176	AUC
Macintyre Cr	nuSEDS	2009	9-Oct-09	23-Dec-09		6				48	AUC
Macintyre Cr	nuSEDS	2010	15-Oct-10	10-Jan-11		6				78	AUC
Macintyre Cr	nuSEDS	2011	7-Oct-11	30-Dec-11		5				50	AUC
Macintyre Cr	nuSEDS	1997	2-Dec-97	9-Jan-98		3				3	Unk.

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Macintyre Cr	nuSEDS	1998								347	Unk.
Macintyre Cr	nuSEDS	1999	15-Oct-99	10-Jan-00		9				907	Unk.
Macintyre Cr	nuSEDS	2000								118	Unk.
Macintyre Cr	nuSEDS	2002	8-Oct-02	14-Jan-03		5				240	AUC
Macintyre Cr	DFO	2004	30-Sep-04	13-Dec-04	6	10	23-Nov-04	57	3.8	214	AUC
Macintyre Cr	DFO	2008	31-Oct-08	15-Jan-09		2		14	3.2	45	PCExp
Macintyre Cr	DFO	2009	2-Nov-09	23-Dec-09		7	27-Nov-09	4	4.1	16	PCExp
Macintyre Cr	DFO	2010	28-Oct-10	11-Jan-11	5	9	11-Nov-10	49	2.4	119	AUC
Macintyre Cr	DFO	2011	7-Oct-11	30-Dec-11	6	10	17-Nov-11	13	4.9	63	AUC
Macintyre Cr	DFO	2012	11-Oct-12	21-Dec-12	6	11	14-Dec-12	27	4.2	115	AUC
Macintyre Cr	DFO	2013	8-Oct-13	27-Jan-14	7	16	3-Dec-13	269	2.4	639	AUC
Macintyre Cr	DFO	2014	17-Oct-14	15-Jan-15	6	13	19-Dec-14	21	6.0	127	AUC
Macintyre Cr	DFO	2015	8-Oct-15	26-Jan-16	11	12		40	4.4	177	AUC
Maria Slough	DFO	2004	29-Sep-04	29-Sep-04		1		0		0	NO
Mclennan Cr	nuSEDS	1997								N/A	N/A
Nathan Cr	nuSEDS	1997	5-Dec-97	27-Jan-98		2				25	Unk.
Nathan Cr	nuSEDS	1998								347	Unk.
Nathan Cr	nuSEDS	1999	18-Oct-99	9-Dec-99		8				1066	Unk.
Nathan Cr	nuSEDS	2000								2368	Unk.
Nathan Cr	nuSEDS	2001	26-Oct-01	21-Jan-02		13				2233	AUC
Nathan Cr	nuSEDS	2002	4-Nov-02	13-Jan-03		6				2481	AUC
Nathan Cr	DFO	2004	21-Oct-04	3-Jan-05	7	9	10-Nov-04	160	4.5	723	AUC
Nathan Cr	DFO	2005	21-Oct-05	11-Jan-06	5	9	22-Nov-05	99	3.1	312	AUC
Nathan Cr	DFO	2006	25-Oct-06	29-Dec-06	26	6	20-Nov-06	65	3.6	232	PCExp
Nathan Cr	DFO	2008	27-Oct-08	30-Jan-09	21	8	17-Nov-08	114	3.4	388	AUC
Nesakwatch Cr	nuSEDS	1997								50	Unk.
Nesakwatch Cr	nuSEDS	1998								125	Unk.
Norrish Cr	nuSEDS	1997								600	Unk.
Norrish Cr	nuSEDS	1998								1000	Unk.

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Norrish Cr	nuSEDS	2001	8-Nov-01	22-Jan-02		11				947	AUC
Norrish Cr	nuSEDS	2002	7-Oct-02	7-Feb-03		5				502	AUC
Norrish Cr	DFO	2004	1-Oct-04	3-Jan-05	17	12	29-Nov-04	440	2.4	1040	AUC
North Alouette R	nuSEDS	1997	10-Nov-97	10-Nov-97		1				N/A	Unk.
North Alouette R	DFO	2004	15-Oct-04	13-Dec-04	5	8	13-Dec-04	70	2.7	190	AUC
Or Cr	nuSEDS	1997								N/A	N/A
Paleface Cr	nuSEDS	1997								15	Unk.
Paleface Cr	nuSEDS	1998								10	Unk.
Peach Cr	nuSEDS	1997								10	Unk.
Peach Cr	nuSEDS	1998								20	Unk.
Peach Cr	DFO	2004	18-Oct-04	17-Dec-04	10	8		78	2.5	197	AUC
Peach Cr	DFO	2005	2-Dec-05	19-Jan-06	5	6	5-Jan-06	8	3.3	26	AUC
Peach Cr	DFO	2006	25-Sep-06	11-Jan-07	7	16	14-Nov-06	16	2.4	39	AUC
Peach Cr	DFO	2008	3-Oct-08	29-Dec-08	8	12	3-Dec-08	2	3.2	6	PCExp
Peach Cr	DFO	2009	10-Nov-09	21-Jan-10	7	8	8-Dec-09	3	7.5	22	AUC
Peach Cr	DFO	2010	11-Oct-10	31-Jan-11	14	16	13-Dec-10	20	4.4	88	AUC
Peach Cr	DFO	2011	12-Oct-11	10-Jan-12	7	13	5-Dec-11	5	4.5	22	AUC
Peach Cr	DFO	2012	15-Oct-12	3-Jan-13	7	11	11-Dec-12	7	3.6	25	AUC
Peach Cr	DFO	2013	7-Oct-13	5-Feb-14	21	16	14-Jan-14	31	4.5	138	AUC
Peach Cr	DFO	2014	6-Oct-14	14-Jan-15	8	14	22-Dec-14	18	4.3	78	AUC
Peach Cr	DFO	2015	5-Oct-15	6-Jan-16	8	13	14-Dec-15	7	1.5	11	AUC
Post Cr	nuSEDS	1997								150	Unk.
Post Cr	nuSEDS	1998								180	Unk.
Post Cr	nuSEDS	1999	14-Oct-99	24-Jan-00		13				4888	Unk.
Post Cr	nuSEDS	2000								1714	Unk.
Post Cr	nuSEDS	2001	22-Oct-01	24-Jan-02		12				1693	AUC
Post Cr	nuSEDS	2002	30-Oct-02	20-Jan-03		10				1088	AUC
Post Cr	nuSEDS	2004	15-Oct-04	2-Feb-05		9				1207	AUC
Post Cr	DFO	2004	15-Oct-04	2-Feb-05	8	13	23-Dec-04	192	6.9	1323	AUC

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Post Cr	SEP	2004	29-Oct-04	2-Feb-05	7	12	17-Dec-04	479	4.8	2292	AUC
Post Cr	SEP	2005	22-Oct-05	28-Dec-05	6	13	29-Dec-05	72	4.3	309	AUC
Post Cr	DFO	2005	27-Oct-05	5-Jan-06	5	10	28-Dec-05	51	4.3	218	AUC
Post Cr	SEP	2006	21-Oct-06	9-Jan-07	5	11	14-Dec-06	37	6.0	220	AUC
Post Cr	DFO	2006	2-Nov-06	9-Jan-07	12	9	21-Nov-06	38	5.2	199	AUC
Post Cr	SEP	2007	23-Oct-07	24-Jan-08	3	15	18-Dec-07	391	5.0	1952	AUC
Post Cr	SEP	2008	31-Oct-08	2-Feb-09	5	12	16-Dec-08	43	3.8	165	AUC
Post Cr	DFO	2008	20-Nov-08	2-Feb-09	25	8	3-Dec-08	37	0.0		AUC
Post Cr	DFO	2009	10-Nov-09	26-Jan-10	20	12	24-Nov-09	75	5.2	386	AUC
Post Cr	SEP	2009	28-Oct-09	30-Dec-09	3	10	30-Nov-09	83	4.6	385	AUC
Post Cr	SEP	2010	25-Oct-10	31-Jan-11	10	21	13-Dec-10	255	1.4	360	AUC
Post Cr	SEP	2011	28-Oct-11	6-Feb-12	4	24	4-Jan-12	203	2.5	502	AUC
Post Cr	SEP	2012	26-Oct-12	10-Jan-13	4	11	14-Dec-12	157	4.8	750	AUC
Post Cr	DFO	2012	12-Nov-12	29-Jan-13	14	11	4-Dec-12	138	5.6	766	AUC
Post Cr	DFO	2013	4-Nov-13	13-Feb-14	10	15	3-Jan-14	263	6.9	1808	AUC
Post Cr	SEP	2013	7-Nov-13	25-Jan-14	7	5	10-Jan-14	292	4.5	1314	AUC
Post Cr	DFO	2014	20-Nov-14	29-Jan-15	14	9	11-Dec-14	205	4.8	983	AUC
Post Cr	DFO	2015	2-Nov-15	28-Jan-16	7	12	14-Dec-15	79	4.8	377	AUC
Purcell Cr	nuSEDS	1997								N/A	N/A
R4 Channel	nuSEDS	1997								0	N/A
R4 Channel	nuSEDS	1998								45	Unk.
Railway Cr	DFO	2011	11-Oct-11	30-Jan-12	7	14	1-Dec-11	34	4.0	135	AUC
Railway Cr	DFO	2012	10-Oct-12	31-Jan-13	6	16	10-Dec-12	25	2.8	70	AUC
Railway Cr	DFO	2013	30-Oct-13	31-Jan-14	7	13	31-Dec-13	136	3.0	404	AUC
Railway Cr	DFO	2014	10-Oct-14	30-Jan-15	6	16	10-Dec-14	74	4.3	321	AUC
Railway Cr	DFO	2015	7-Oct-15	3-Feb-16	7	17	8-Dec-15	34	5.9	202	AUC
Range Cr	nuSEDS	1997								400	Unk.
Range Cr	nuSEDS	1998								385	Unk.
Range Cr	SEP	2012	26-Oct-12	16-Jan-13	5	9	14-Nov-12	21	5.1	107	AUC

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Ryder Cr / Lovely Pond	nuSEDS	1998								40	Unk.
Ryder Cr / Lovely Pond	SEP	2004	29-Oct-04	4-Jan-05	18	9	16-Nov-04	40	5.2	206	AUC
Ryder Cr / Lovely Pond	SEP	2005	5-Nov-05	17-Jan-06	5	11	23-Dec-05	54	2.3	122	AUC
Ryder Cr / Lovely Pond	SEP	2006	31-Oct-06	5-Jan-07	8	9	22-Nov-06	19	3.5	67	AUC
Ryder Cr / Lovely Pond	SEP	2007	26-Oct-07	16-Jan-08	7	13	18-Dec-07	38	4.6	174	AUC
Ryder Cr / Lovely Pond	SEP	2009	28-Oct-09	31-Dec-09	8	9	23-Nov-09	22	3.5	77	AUC
Ryder Cr / Lovely Pond	SEP	2010	28-Oct-10	29-Dec-10	5	10	3-Dec-10	42	4.4	184	AUC
Ryder Cr / Lovely Pond	SEP	2011	4-Nov-11	15-Dec-11	13	6	15-Dec-11	9	2.3	21	AUC
Ryder Cr / Lovely Pond	SEP	2012	18-Oct-12	26-Nov-12	7	5	14-Nov-12	153	1.9	284	AUC
Salmon R	nuSEDS	1997								4193	Mark & Recapture: Petersen
Salmon R	nuSEDS	1998								3281	Mark & Recapture: Petersen
Salmon R	nuSEDS	1999								2247	Mark & Recapture: Petersen
Salmon R	nuSEDS	2000								6211	Mark & Recapture: Petersen

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Salmon R	nuSEDS	2001								7298	Mark & Recapture: Petersen
Salmon R	nuSEDS	2002				NA				5533	Mark & Recapture: Petersen
Salmon R	nuSEDS	2003				NA				3587	Mark & Recapture: Petersen
Salmon R	nuSEDS	2004	18-Oct-04	1-Feb-05		NA				5591	Mark & Recapture: Petersen
Salmon R	nuSEDS	2006	26-Oct-06	26-Jan-07		NA				1377	Mark & Recapture: Petersen
Salmon R	nuSEDS	2007	19-Oct-07	30-Jan-08		NA				2071	Mark & Recapture: Petersen
Salmon R	nuSEDS	2008	2-Nov-08	9-Dec-08		NA				1121	Mark & Recapture: Petersen
Salmon R	DFO	2009	9-Dec-09	9-Dec-09		1		60	4.1	247	PCExp
Salwein Cr	nuSEDS	1997								40	Unk.
Salwein Cr	nuSEDS	1998								90	Unk.
Salwein Cr	SEP	2004	26-Nov-04	22-Feb-05	4	12	25-Jan-05	163	3.7	601	AUC
Salwein Cr	SEP	2005	21-Nov-05	17-Jan-06	8	10	28-Dec-05	64	1.9	119	NO
Salwein Cr	SEP	2006	5-Dec-06	11-Jan-07	7	6	22-Jan-00	22	1.8	39	AUC
Salwein Cr	SEP	2007	7-Nov-07	22-Jan-08	14	10	17-Dec-07	16	3.0	48	AUC
Salwein Cr	SEP	2008	19-Nov-08	30-Jan-09	7	10	14-Jan-09	17	1.6	27	NO
Salwein Cr	SEP	2009	12-Nov-09	28-Jan-10	12	12	7-Jan-10	24	3.6	85	NO

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Salwein Cr	SEP	2010	9-Nov-10	18-Jan-11	24	8	17-Dec-10	212	2.7	562	AUC
Salwein Cr	SEP	2011	17-Nov-11	18-Jan-12	8	8	4-Jan-12	128	3.3	429	AUC
Salwein Cr	SEP	2012	7-Nov-12	15-Jan-13	7	11	15-Jan-13	119	4.1	485	AUC
Salwein Cr	SEP	2013	28-Oct-13	29-Jan-14	8	11	8-Jan-14	257	1.8	474	AUC
Schoolhouse Cr	nuSEDS	1997								70	Unk.
Scott Cr	nuSEDS	1997								N/A	N/A
Siddle Cr	nuSEDS	2001	5-Nov-01	22-Jan-02		10				1706	AUC
Siddle Cr	nuSEDS	2002	9-Oct-02	16-Jan-03		7				837	AUC
Siddle Cr	DFO	2004	20-Oct-04	24-Jan-05	7	13	3-Dec-04	242	5.1	1226	AUC
Siddle Cr	DFO	2005	14-Oct-05	19-Jan-06	11	12	23-Dec-05	155	3.0	466	AUC
Siddle Cr	DFO	2006	3-Nov-06	10-Jan-07	6	10	16-Nov-06	79	3.1	245	AUC
Siddle Cr	DFO	2009	16-Nov-09	27-Jan-10	15	11	23-Nov-09	152	3.7	564	AUC
Siddle Cr	DFO	2010	9-Nov-10	3-Feb-11	14	14	16-Nov-10	337	4.4	1489	AUC
Siddle Cr	DFO	2011	11-Nov-11	31-Jan-12	7	12	1-Dec-11	155	4.1	638	AUC
Siddle Cr	DFO	2012	6-Nov-12	7-Feb-13	14	12	27-Nov-12	109	5.5	605	AUC
Siddle Cr	DFO	2013	3-Oct-13	13-Feb-14	27	16	26-Nov-13	603	5.0	3042	AUC
Siddle Cr	DFO	2014	12-Nov-14	30-Jan-15	8	8	17-Dec-14	127	4.9	616	AUC
Siddle Cr	DFO	2015	7-Oct-15	29-Jan-16	7	16	10-Nov-15	74	4.8	354	AUC
Silverdale Cr	nuSEDS	1997								200	Unk.
Silverdale Cr	nuSEDS	2001	13-Nov-01	22-Jan-02		6				317	AUC
Silverdale Cr	nuSEDS	2002	10-Oct-02	13-Jan-03		12				373	AUC
Silverdale Cr	DFO	2004	30-Sep-04	3-Jan-05	6	11	1-Dec-04	67	4.8	323	AUC
Silverdale Cr	DFO	2005	24-Oct-05	3-Jan-06	5	9	3-Jan-06	32	2.6	84	AUC
Silverdale Cr	DFO	2006	29-Sep-06	28-Dec-06	17	8	20-Nov-06	8	3.2	26	AUC
Silverdale Cr	DFO	2008	2-Oct-08	22-Jan-09	6	15	4-Dec-08	23	4.9	113	AUC
Silverdale Cr	DFO	2009	5-Nov-09	27-Jan-10	5	9	25-Nov-09	20	2.7	54	AUC
Silverdale Cr	DFO	2010	8-Oct-10	1-Feb-11	12	14	3-Nov-10	78	3.4	263	AUC
Silverdale Cr	DFO	2011	10-Oct-11	27-Jan-12	7	15	29-Nov-11	62	3.4	208	AUC
Silverdale Cr	DFO	2012	9-Oct-12	22-Jan-13	9	12	28-Nov-12	39	3.8	147	AUC

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Silverdale Cr	DFO	2013	4-Oct-13	30-Jan-14	14	15	28-Nov-13	60	5.4	325	AUC
Silverdale Cr	DFO	2014	15-Oct-14	23-Jan-15	5	15	8-Dec-14	26	5.7	148	AUC
Silverdale Cr	DFO	2015	6-Oct-15	25-Jan-16	9	13	21-Dec-15	27	5.0	136	AUC
Sless Cr	nuSEDS	1997								650	Unk.
Sless Cr	nuSEDS	1998								3000	Unk.
South Alouetter River	nuSEDS	1997	10-Nov-97	10-Nov-97		1				375	Unk.
South Alouette	FRCC-ARMS	2003								51	Fence
South Alouette	FRCC-ARMS	2005								451	Fence
South Alouette	FRCC-ARMS	2006								146	Fence
South Alouette	FRCC-ARMS	2007								298	Fence
South Alouette	FRCC-ARMS	2008								273	Fence
South Alouette	FRCC-ARMS	2009								78	Fence
South Alouette	FRCC-ARMS	2010								339	Fence
South Alouette	FRCC-ARMS	2011								628	Fence
South Alouette	FRCC-ARMS	2012								52	Fence
Squawkum Cr	nuSEDS	2002	7-Oct-02	12-Feb-03		7				118	AUC
Squawkum Cr	DFO	2004	8-Oct-04	10-Feb-05	10	17	24-Jan-05	100	3.0	301	AUC
Squawkum Cr	DFO	2005	12-Oct-05	5-Jan-06	44	6	30-Dec-05	25	3.3	83	AUC
Squawkum Cr	DFO	2006	29-Sep-06	10-Jan-07	24	10	14-Dec-06	9	3.4	31	AUC
Squawkum Cr	DFO	2008	6-Oct-08	29-Jan-09	8	16	12-Jan-09	28	3.0	83	AUC
Squawkum Cr	DFO	2009	3-Nov-09	1-Feb-10	9	13	10-Dec-09	33	3.5	117	AUC
Squawkum Cr	DFO	2010	6-Oct-10	10-Feb-11	37	15	15-Dec-10	110	4.2	458	AUC
Squawkum Cr	DFO	2011	5-Oct-11	6-Feb-12	6	18	5-Jan-12	78	2.9	223	AUC
Squawkum Cr	DFO	2012	10-Oct-12	7-Feb-13	6	17	10-Dec-12	55	4.2	230	AUC
Squawkum Cr	DFO	2013	3-Oct-13	7-Feb-14	27	15	17-Jan-14	632	3.1	1956	AUC
Squawkum Cr	DFO	2014	10-Oct-14	30-Jan-15	6	16	24-Dec-14	77	4.8	372	AUC
Squawkum Cr	DFO	2015	7-Oct-15	29-Jan-16	7	16	5-Jan-16	38	3.4	130	AUC
Stoney Cr	nuSEDS	1997								10	Unk.

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Stoney Cr	Stoney Creek Environment Committee	2006								38	TBD
Stoney Cr	Stoney Creek Environment Committee	2007								63	TBD
Stoney Cr	Stoney Creek Environment Committee	2008								60	TBD
Stoney Cr	Stoney Creek Environment Committee	2009								26	TBD
Stoney Cr	Stoney Creek Environment Committee	2010								241	TBD
Stoney Cr	Stoney Creek Environment Committee	2011								167	TBD
Stoney Cr	Stoney Creek Environment Committee	2012								47	TBD
Stoney Cr	Stoney Creek Environment Committee	2013								405	TBD
Stoney Cr	Stoney Creek Environment Committee	2014								101	TBD
Stoney Cr	Stoney Creek Environment Committee	2015								79	TBD
Street Cr	nuSEDS	1997								25	Unk.

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Street Cr	nuSEDS	1998								30	Unk.
Street Cr	nuSEDS	1999	14-Oct-99	20-Jan-00		8				98	Unk.
Street Cr	nuSEDS	2000								7	Unk.
Street Cr	nuSEDS	2001	23-Oct-01	30-Jan-02		6				31	AUC
Street Cr	nuSEDS	2002	30-Sep-02	20-Jan-03		4				11	AUC
Street Cr	DFO	2004	7-Oct-04	9-Feb-05	11	15	27-Jan-05	6	3.2	19	AUC
Street Cr	DFO	2005	12-Oct-05	12-Oct-05		1		0		0	NO
Street Cr	DFO	2009	10-Nov-09	12-Jan-10	7	10	24-Dec-09	2	4.1	8	PCExp
Street Cr	DFO	2010	25-Oct-10	31-Jan-11	7	15	13-Dec-10	39	2.7	106	AUC
Street Cr	DFO	2011	12-Oct-11	23-Jan-12	7	15	28-Dec-11	15	2.0	31	AUC
Street Cr	DFO	2012	15-Oct-12	29-Jan-13	7	15	9-Jan-13	14	3.7	52	AUC
Street Cr	DFO	2013	7-Oct-13	5-Feb-14	7	18	14-Jan-14	80	2.9	235	AUC
Street Cr	DFO	2014	14-Oct-14	21-Jan-15	7	14	22-Dec-14	19	3.7	70	AUC
Street Cr	DFO	2015	5-Oct-15	3-Feb-16	8	17	9-Dec-15	4	5.2	21	AUC
Sweltzer River	nuSEDS	1997								0	N/A
Sweltzer River	nuSEDS	1998								N/A	N/A
Sweltzer River	DFO	2008	20-Nov-08	23-Dec-08	10	6	20-Nov-08	20	1.8	36	AUC
Tamihi Cr	nuSEDS	1997								N/A	N/A
Thurston Cr	nuSEDS	1997								150	Unk.
Thurston Cr	nuSEDS	1998								100	Unk.
Tipella Cr	nuSEDS	1997								N/A	N/A
Tipella Cr	Douglas	2004	14-Oct-04	12-Jan-05	6	12	10-Nov-04	28	6.2	173	AUC
Tipella Cr	Douglas	2005	15-Sep-05	11-Jan-06	10	13	15-Sep-05	3	3.6	11	PCExp
Tipella Cr	Douglas	2006	1-Sep-06	13-Dec-06	11	10	7-Dec-06	14	3.6	50	PCExp
Tipella Cr	Douglas	2008	23-Oct-08	4-Dec-08	21	3	4-Dec-08	10	3.2	32	PCExp
Tipella Cr	Douglas	2010	6-Oct-10	10-Feb-11	8	19	18-Nov-10	38	5.0	188	AUC
Tipella Cr	Douglas	2011	22-Sep-11	9-Feb-12	7	19	1-Dec-11	25	6.6	164	AUC
Tipella Cr	Douglas	2012	11-Oct-12	27-Feb-13	7	21	8-Nov-12	54	5.9	318	AUC
Upper Pitt River	nuSEDS	1997								9836	Unk.

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Upper Pitt River	nuSEDS	1998								8296	Unk.
Usher Channel	nuSEDS	1997								5	Unk.
Usher Channel	nuSEDS	1998								10	Unk.
Wahleach Cr	nuSEDS	1997								N/A	N/A
West Cr	nuSEDS	1997								N/A	N/A
West Cr	nuSEDS	2000								1141	Unk.
West Cr	nuSEDS	2001	26-Oct-01	21-Jan-02		11				1201	AUC
Whonnock Cr	nuSEDS	1997	2-Dec-97	12-Jan-98		3				17	Unk.
Whonnock Cr	nuSEDS	1998								496	Unk.
Whonnock Cr	nuSEDS	1999	13-Oct-99	19-Jan-00		13				950	Unk.
Whonnock Cr	nuSEDS	2000								580	Unk.
Whonnock Cr	nuSEDS	2001	24-Oct-01	22-Jan-02		11				1408	AUC
Whonnock Cr	nuSEDS	2002	8-Oct-02	17-Jan-03		7				987	AUC
Whonnock Cr	DFO	2004	19-Oct-04	5-Jan-05	7	10	17-Nov-04	147	4.7	684	AUC
Whonnock Cr	DFO	2005	24-Oct-05	11-Jan-06	16	9	18-Nov-05	33	4.1	136	AUC
Whonnock Cr	DFO	2006	13-Nov-06	2-Jan-07	10	1	28-Dec-06	3	3.6	11	PCExp
Whonnock Cr	DFO	2009	7-Dec-09	6-Jan-10	15	1	7-Dec-09	28	4.1	115	PCExp
Whonnock Cr	DFO	2012	9-Oct-12	13-Dec-12	11	9	9-Nov-12	11	4.2	46	AUC
Whonnock Cr	DFO	2013	4-Oct-13	6-Dec-13	10	8	21-Nov-13	19	3.8	71	AUC
Whonnock Cr	DFO	2014	15-Oct-14	23-Dec-14	12	11	24-Nov-14	13	2.5	32	AUC
Whonnock Cr	DFO	2015	6-Oct-15	30-Nov-15	9	8	5-Nov-15	27	1.7	46	AUC
Widgeon Cr	nuSEDS	1997								N/A	N/A
Widgeon Cr	nuSEDS	2000								933	Unk.
Widgeon Cr	nuSEDS	2001	2-Nov-01	25-Jan-02		7				2393	AUC
Widgeon Cr	DFO	2004	15-Oct-04	7-Dec-04	4	9	30-Nov-04	388	4.1	1585	AUC
Widgeon Cr	DFO	2009	23-Oct-09	29-Jan-10	10	12	27-Nov-09	36	2.0	71	AUC
Widgeon Cr	DFO	2010	15-Oct-10	27-Jan-11	7	13	11-Nov-10	156	4.9	771	AUC
Widgeon Cr	DFO	2011	7-Oct-11	12-Jan-12	6	14	17-Nov-11	213	4.4	946	AUC
Widgeon Cr	DFO	2012	11-Oct-12	28-Jan-13	6	11	11-Jan-13	25	6.2	154	AUC

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Widgeon Cr	DFO	2013	8-Oct-13	4-Feb-14	7	17	3-Dec-13	632	4.2	2652	AUC
Widgeon Cr	DFO	2014	17-Oct-14	22-Jan-15	7	12	25-Nov-14	132	3.7	492	AUC
Widgeon Cr	DFO	2015	8-Oct-15	26-Jan-16	11	12	16-Nov-15	99	2.8	276	AUC
Wingfield Cr	SEP	2007	7-Nov-07	16-Jan-08	6	10	18-Dec-07	38	3.0	115	AUC
Wingfield Cr	SEP	2008	7-Nov-08	21-Jan-09	13	7	13-Nov-08	2	3.2	6	PCExp
Wingfield Cr	SEP	2009	28-Oct-09	17-Dec-09	8	8	30-Nov-09	5	2.1	11	AUC
Wingfield Cr	SEP	2010	8-Nov-10	29-Dec-10	5	8	15-Dec-10	111	2.2	248	AUC
Wingfield Cr	SEP	2011	6-Nov-11	15-Dec-11	11	6	17-Nov-11	3	2.9	9	AUC
Wingfield Cr	SEP	2012	6-Nov-12	16-Jan-13	5	9	28-Dec-12	19	2.9	56	AUC
Worth Cr	nuSEDS	2001	8-Nov-01	30-Jan-02		12				1982	AUC
Worth Cr	nuSEDS	2002	7-Oct-02	12-Feb-03		11				819	AUC
Worth Cr	DFO	2004	5-Oct-04	10-Feb-05	13	19	20-Dec-04	168	3.6	602	AUC
Worth Cr	DFO	2005	14-Oct-05	19-Jan-06	18	10	30-Dec-05	174	2.7	472	AUC
Worth Cr	DFO	2006	29-Sep-06	1-Feb-07	3	16	14-Dec-06	80	4.2	339	AUC
Worth Cr	DFO	2008	6-Oct-08	29-Jan-09	22	13	12-Jan-09	75	4.5	340	AUC
Worth Cr	DFO	2009	6-Nov-09	8-Feb-10	5	21	13-Jan-10	155	5.1	789	AUC
Worth Cr	DFO	2010	5-Oct-10	3-Feb-11	31	15	15-Dec-10	221	3.2	716	AUC
Worth Cr	DFO	2011	4-Oct-11	5-Feb-12	7	18	29-Dec-11	468	2.4	1117	AUC
Worth Cr	DFO	2012	10-Oct-12	8-Feb-13	6	17	3-Dec-12	275	3.6	987	AUC
Worth Cr	DFO	2013	3-Oct-13	7-Feb-14	7	17	31-Dec-13	169	5.0	845	AUC
Worth Cr	DFO	2014	10-Oct-14	30-Jan-15	6	16	10-Dec-14	239	3.5	842	AUC
Worth Cr	DFO	2015	7-Oct-15	3-Feb-16	7	17	18-Dec-15	107	3.4	364	AUC
Yorkson Cr	nuSEDS	1997								N/A	N/A

Table B3. Lillooet CU Escapement meta data summary. TribDeme refers to the common name of the system, Affiliation references the agency responsible for the estimate, First and Last Dates are the first and last dates a survey was attempted, Interval (days) refers to the number of days between surveys, Total Surveys refers to the total surveys attempted in each year, Peak Data and Count refer to the date the peak escapement was observed and what it was observed as, Expansion refers to the ratio of peak count to final estimate, Final estimate is the best estimate of escapement, if possible, Type refers to how the Final escapement estimate was generated.

			Survey Information				**Peak**			**Escapement**	
TribDeme	**Affiliation**	**Year**	**First Date**	**Last Date**	**Interval (days)**	**Total surveys**	**Date**	**Count**	**Expansion**	**Final**	**Type**
1 Mile Lake	Lil'wat	2014	24-Oct-14	10-Dec-14	47	2	10-Dec-14	12	4.2	50	PCExp
1 Mile Lake	Lil'wat	2015	18-Nov-15	18-Nov-15		1	18-Nov-15	3	3.9	12	PCExp
Alena Cr	Lil'wat	2012	26-Oct-12	16-Nov-12	11	3	16/11//2012	9	4.3	39	PCExp
Alena Cr	Lil'wat	2015	24-Nov-15	18-Dec-15	8	4	18-Dec-15	1	3.9	4	PCExp
Birkenhead R	nuSEDS	1997								N/A	N/A
Birkenhead R	Lil'wat	2004	19-Oct-04	4-Jan-05	7	23	22-Nov-04	1797	4.3	7746	AUC
Birkenhead R	Lil'wat	2005	7-Nov-05	18-Jan-06	7	16	28-Nov-05	109	3.8	411	AUC
Birkenhead R	Lil'wat	2006	23-Oct-06	28-Nov-06	7	11	14-Nov-06	195	2.6	507	AUC
Birkenhead R	Lil'wat	2007	22-Oct-07	25-Jan-08	7	28	26-Nov-07	410	4.4	1801	AUC
Birkenhead R	Lil'wat	2008	20-Oct-08	27-Jan-09	7	30	11-Nov-08	339	1.9	658	AUC
Birkenhead R	Lil'wat	2009	19-Oct-09	26-Jan-10	1	32	23-Nov-09	207	4.5	939	AUC
Birkenhead R	Lil'wat	2011	22-Nov-11	24-Jan-12	21	17	12-Dec-11	389	2.3	884	AUC
Birkenhead R	Lil'wat	2012	1-Oct-12	29-Jan-13	17	36	4-Dec-12	869	4.1	3581	AUC
Birkenhead R	Lil'wat	2013	8-Oct-13	7-Jan-14	20	16	18-Nov-13	632	3.6	2284	AUC
Birkenhead R	Lil'wat	2014	21-Oct-14	16-Dec-14	15	16	25-Nov-14	222	3.4	765	AUC
Birkenhead R	Lil'wat	2015	2-Nov-15	29-Dec-15	8	10	30-Nov-15	8	2.6	21	AUC
Chief Paul Cr	Douglas	2006	13-Oct-06	28-Nov-06	15	4	13-Oct-06	6	3.6	21	PCExp
Chief Paul Cr	Douglas	2008	3-Oct-08	5-Dec-08	16	5		0		0	NO
Chief Paul Cr	Douglas	2010	22-Oct-10	22-Dec-10	20	4	22-Dec-10	2	3.8	8	PCExp
Chief Paul Cr	Douglas	2011	30-Sep-11	24-Nov-11	55	2	30-Sep-11	10	3.8	38	PCExp
Chief Paul Cr	Douglas	2012	17-Oct-12	20-Nov-12	34	2				0	NO
Crazy Cr	Douglas	2004	20-Oct-04	1-Feb-05	7	13	22-Dec-04	123	3.3	405	AUC
Crazy Cr	Douglas	2005	12-Sep-05	18-Jan-06	3	14	9-Nov-05	80	6.1	487	AUC
Crazy Cr	Douglas	2006	2-Nov-06	21-Dec-06	14	8	7-Dec-06	118	2.1	244	AUC

			Survey Information				Peak			Escapement	
TribDeme	**Affiliation**	**Year**	**First Date**	**Last Date**	**Interval (days)**	**Total surveys**	**Date**	**Count**	**Expansion**	**Final**	**Type**
Crazy Cr	Douglas	2008	13-Nov-08	4-Dec-08	10	3	4-Dec-08	124	2.9	364	AUC
Crazy Cr	Douglas	2010	8-Oct-10	9-Feb-11	12	14	8-Dec-10	59	3.7	218	AUC
Crazy Cr	Douglas	2011	22-Sep-11	9-Feb-12	7	19	1-Dec-11	27	4.9	131	AUC
Crazy Cr	Douglas	2012	25-Oct-12	28-Feb-13	7	19	6-Dec-12	76	7.6	576	AUC
Douglas Cr	nuSEDS	1997								N/A	N/A
Douglas Cr	Douglas	2004	11-Oct-04	16-Dec-04	10	10	2-Dec-04	22	2.9	63	AUC
Douglas Cr	Douglas	2005	6-Sep-05	12-Jan-06	9	15	8-Dec-05	1	3.6	4	PCExp
Douglas Cr	Douglas	2006	11-Oct-06	1-Dec-06	9	7	16-Oct-16	1	3.6	4	PCExp
Douglas Cr	Douglas	2008	4-Nov-08	1-Dec-08	9	4	24-Nov-08	6	3.2	19	PCExp
Douglas Cr	Douglas	2010	5-Nov-10	11-Feb-11	7	13	19-Nov-10	18	3.9	70	AUC
Douglas Cr	Douglas	2011	4-Nov-11	10-Feb-12	8	13	5-Dec-11	10	3.8	38	PCExp
Douglas Cr	Douglas	2012	12-Oct-12	22-Feb-13	7	20	21-Dec-12	28	4.9	138	AUC
Fee Creek	nuSEDS	1997								125	Unk.
Fire Cr	Douglas	2005	18-Nov-05	9-Dec-05	21	2		0		0	NO
Green R	nuSEDS	1997								N/A	N/A
Green R	Lil'wat	2004	22-Oct-04	24-Dec-04	7	9	2-Dec-04	276	2.8	768	AUC
Green R	Lil'wat	2005	4-Nov-05	15-Dec-05	5	7	8-Dec-05	47	2.9	136	AUC
Green R	Lil'wat	2006	10-Nov-06	30-Nov-06	20	2		0		0	NO
Green R	Lil'wat	2007	1-Nov-07	11-Jan-08	21	8	13-Dec-07	125	3.4	422	AUC
Green R	Lil'wat	2008	24-Oct-08	21-Nov-08	14	3		0		0	NO
Green R	Lil'wat	2009	22-Oct-09	4-Dec-09	11	5	4-Dec-09	34	4.1	140	PCExp
Green R	Lil'wat	2012	15-Nov-12	24-Jan-13	15	4	30-Nov-12	14	5.1	72	AUC
Green R	Lil'wat	2013	22-Nov-13	3-Jan-14	21	3	3-Jan-14	22	4.2	92	PCExp
Green R	Lil'wat	2014	24-Oct-14	10-Dec-14	24	3				0	NO
Green R	Lil'wat	2015	4-Nov-15	16-Dec-15	7	7	20-Nov-15	3	1.7	5	AUC
Heritage Cr	Douglas	2004	4-Nov-04	2-Dec-04	10	4	2-Dec-04	6	4.0	24	PCExp
Heritage Cr	Douglas	2005	8-Dec-05	8-Dec-05		1		0		0	NO
John Sandy Creek	nuSEDS	1997								N/A	N/A
Lillooet R	Douglas	2012	20-Sep-12	20-Sep-12		1	20-Sep-12	4	4.3	17	PCExp

			Survey Information				Peak			Escapement	
TribDeme	Affiliation	Year	First Date	Last Date	Interval (days)	Total surveys	Date	Count	Expansion	Final	Type
Lower Birkenhead Cr	Lil'wat	2004	31-Dec-04	31-Dec-04		1	31-Dec-04	6	4.0	24	PCExp
Mckenzie Creek	nuSEDS	1997								N/A	N/A
Miller Cr	nuSEDS	1997								N/A	N/A
Old Courthouse Cr	Douglas	2005	27-Oct-05	27-Oct-05		1	27-Oct-05	1	3.6	4	PCExp
Old Courthouse Cr	Douglas	2006	24-Nov-06	17-Dec-06	12	3	2-Dec-06	2	3.6	7	PCExp
Old Courthouse Cr	Douglas	2008	24-Nov-08	1-Dec-08	7	2		0		0	NO
Old Courthouse Cr	Douglas	2011	7-Oct-11	10-Feb-12	10	14	2-Dec-11	8	3.8	31	PCExp
Old Courthouse Cr	Douglas	2012	12-Oct-12	22-Feb-13	7	20	16-Nov-12	8	3.3	27	AUC
Pemberton Cr	nuSEDS	1997								N/A	N/A
Pemberton Cr	Lil'wat	2008	13-Nov-08	13-Nov-08		1	13-Nov-08	9	3.2	29	PCExp
Pemberton Cr	Lil'wat	2009	15-Oct-09	22-Oct-09	7	2		0		0	NO
Pemberton Cr	Lil'wat	2012	1-Nov-12	3-Jan-13	30	3	30-Nov-12	7	4.3	30	PCExp
Pemberton Cr	Lil'wat	2013	31-Jan-14	31-Jan-14		1	31-Jan-14	1	4.2	4	PCExp
Pemberton Cr	Lil'wat	2015	9-Nov-15	18-Dec-15	10	4	18-Nov-15	2	5.0	10	AUC
Pemberton Cr/One Mile Cr	Lil'wat	2004	21-Oct-04	31-Dec-04	6	8	17-Nov-04	73	3.5	253	AUC
Pemberton Cr/One Mile Cr	Lil'wat	2006	2-Nov-06	2-Nov-06		1		0		0	NO
Pemberton Cr/One Mile Cr	Lil'wat	2007	21-Nov-07	21-Dec-07	10	4	29-Nov-07	18	1.8	32	AUC
Pemberton Inlet	Lil'wat	2012	1-Nov-12	1-Nov-12		1				0	NO
Poole Cr	nuSEDS	1997								N/A	N/A
Poole Cr	Lil'wat	2004	21-Oct-04	31-Dec-04	5	11	15-Dec-04	150	4.3	646	AUC
Poole Cr	Lil'wat	2005	7-Nov-05	5-Jan-06	3	8	14-Dec-05	48	4.6	222	AUC

			Survey Information				Peak			Escapement	
TribDeme	**Affiliation**	**Year**	**First Date**	**Last Date**	**Interval (days)**	**Total surveys**	**Date**	**Count**	**Expansion**	**Final**	**Type**
Poole Cr	Lil'wat	2006	25-Oct-06	22-Nov-06	7	5	16-Nov-06	68	3.3	224	AUC
Poole Cr	Lil'wat	2007	31-Oct-07	17-Jan-08	7	13	5-Dec-07	174	4.9	846	AUC
Poole Cr	Lil'wat	2008	22-Oct-08	4-Dec-08	7	7	13-Nov-08	182	3.1	560	AUC
Poole Cr	Lil'wat	2012	25-Oct-12	16-Jan-13	7	13	5-Dec-12	355	4.4	1552	AUC
Poole Cr	Lil'wat	2013	30-Oct-13	8-Jan-14	7	10	19-Nov-13	353	4.6	1609	AUC
Poole Cr	Lil'wat	2014	22-Oct-14	17-Dec-14	8	9	10-Nov-14	117	4.4	521	AUC
Poole Cr	Lil'wat	2015	4-Nov-15	29-Dec-15	6	10	15-Dec-15	4	1.7	7	AUC
Puska Cr	Douglas	2004	28-Oct-04	28-Oct-04		1		0		0	NO
Railroad Cr	nuSEDS	1997								N/A	N/A
Railroad Cr	Lil'wat	2012	26-Oct-12	14-Dec-12	5	5	6-Dec-12	66	2.3	155	AUC
Railroad Cr	Lil'wat	2014								0	NO
Robb Cr	Lil'wat	2012	7-Dec-12	7-Dec-12		1	7-Dec-12	19	4.3	82	PCExp
Robb Cr	Lil'wat	2015	25-Nov-15	3-Dec-15	4	3	25-Nov-15	1	3.9	4	PCExp
Ryan R	nuSEDS	1997								N/A	N/A
Ryan R	Lil'wat	2005	9-Dec-05	16-Dec-05	7	2	9-Dec-05	26	3.6	94	PCExp
Ryan R	Lil'wat	2006	26-Oct-06	2-Nov-06	7	2		0		0	NO
Ryan R	Lil'wat	2009	1-Dec-09	8-Dec-09	7	2	8-Dec-09	18	4.1	74	PCExp
Ryan R	Lil'wat	2013	8-Nov-13	18-Dec-13	13	4	9-Nov-13	20	4.2	83	PCExp
Ryan R	Lil'wat	2014	15-Oct-14	15-Oct-14		1		0		0	NO
Ryan R	Lil'wat	2015	12-Nov-15	24-Dec-15	7	7	18-Dec-15	3	0.0		
Salmon Slough	nuSEDS	1997								N/A	N/A
Salmon Slough	nuSEDS	1999								N/A	N/A
Salmon Slough	Lil'wat	2004	18-Nov-04	23-Dec-04	15	4	18-Nov-04	160	2.7	439	AUC
Salmon Slough	Lil'wat	2012	7-Dec-12	25-Jan-13	49	2	7-Dec-12	197	4.3	854	PCExp
Sampson Cr	nuSEDS	1997								N/A	N/A
Sampson Cr	Lil'wat	2006	27-Oct-06	30-Nov-06	5	5	9-Nov-06	127	2.9	374	AUC
Sampson Cr	Lil'wat	2010	20-Oct-10	31-Dec-10	7	8	18-Nov-10	293	2.2	644	AUC
Sampson Cr	Lil'wat	2012	26-Oct-12	14-Dec-12	27	5	22-Nov-12	103	3.9	406	AUC
Sampson Cr	Lil'wat	2014	15-Oct-14	27-Nov-14	43	2	27-Nov-14	1	4.2	4	PCExp

			Survey Information				Peak			Escapement	
TribDeme	**Affiliation**	**Year**	**First Date**	**Last Date**	**Interval (days)**	**Total surveys**	**Date**	**Count**	**Expansion**	**Final**	**Type**
Sampson/Railroad	Lil'wat	2004	18-Oct-04	23-Dec-04	10	9	19-Nov-04	408	2.6	1064	AUC
Sampson/Railroad	Lil'wat	2007	10-Oct-07	30-Nov-07	23	6	16-Nov-07	297	2.3	677	AUC
Sampson/Railroad	Lil'wat	2008	25-Sep-08	14-Nov-08	14	5	14-Nov-08	112	2.1	236	AUC
Sampson/Railroad	Lil'wat	2009	16-Oct-09	27-Nov-09	7	6	13-Nov-09	242	3.2	780	AUC
Sampson/Railroad	Lil'wat	2011	17-Nov-11	19-Jan-12	15	8	17-Nov-11	172	1.6	278	AUC
Sampson/Railroad	Lil'wat	2013	8-Nov-13	9-Jan-14	14	8	15-Nov-13	403	3.1	1233	AUC
Sampson/Railroad	Lil'wat	2015	5-Nov-15	31-Dec-15	8	8	10-Dec-15	5	2.6	13	AUC
Sloquet Cr	nuSEDS	1997								N/A	N/A
Sloquet Cr	Douglas	2004	6-Oct-04	1-Feb-05	14	40	22-Nov-04	570	7.3	4185	AUC
Sloquet Cr	Douglas	2005	14-Sep-05	12-Jan-06	6	32	14-Nov-05	581	5.1	2971	AUC
Sloquet Cr	Douglas	2006	10-Oct-06	11-Dec-06	7	20	13-Nov-06	308	3.1	963	AUC
Sloquet Cr	Douglas	2008	7-Oct-08	4-Dec-08	6	20	25-Nov-08	271	4.2	1129	AUC
Sloquet Cr	Douglas	2010	4-Oct-10	8-Feb-11	8	42	25-Nov-10	336	5.0	1670	AUC
Sloquet Cr	Douglas	2011	18-Oct-11	15-Feb-12	6	47	6-Dec-11	598	7.4	4447	AUC
Sloquet Cr	Douglas	2012	9-Oct-12	26-Feb-13	6	51	27-Nov-12	406	5.3	2153	AUC
Snowcap Cr	Douglas	2006	13-Oct-06	23-Oct-06	10	2		0		0	NO
South Cr	Lil'wat	2012	29-Nov-12	29-Nov-12		1				0	NO
Upper Lillooet Cr	Lil'wat	2012	23-Nov-12	23-Nov-12		1				0	NO

APPENDIX C ANCILLARY ANALYSES

Ancillary analyses used to determine simulator properties used the longest consecutive series of escapement observations for each broodline within each PU (Table C1). All analyses employed mixed effect models fit with the `nlme` package in the R computing environment (Pinheiro et al. 2017, R Core Team 2017). Model rankings were performed using the small-sample Akaike Information Criterion (AICc) on models fit using maximum likelihood estimation (Burnham and Anderson 2002; Mazerolle 2017, R Development Core Team 2017).

PU LEVEL EFFECTS

Mixed effect models were used to investigate potential fixed effect structures that should be captured in the simulation model. The following mixed effect model was used:

$$Log\ Escapement = [FIXED] + PU(R)$$

where $[FIXED]$ represents different fixed effect models and $PU(R)$ is a random effect representing the variability between PUs. In total 8 different fixed effect models were fit with maximum likelihood method and ranked by AICc (Table C2). Estimating a separate broodline effect within each CU was found to have the most support and was the basis of the broodline functionality in the simulator.

AUTOCORRELATIONAL EFFECTS

The top model was then used to determine whether autocorrelation existed between escapement observations at the PU level by comparing the support for different autoregressive moving average (ARMA) models (Table C3). The null model (no autocorrelation effect) had the least support and strongest support was for second order effect, as either a second order autoregressive and moving-average effect (i.e., ARMA(2,2)) or a second order moving-average effect (i.e., ARMA(0,2)). Higher order autocorrelation effects were not tested due to convergence issues.

Because these PU-level effects could be the result of local phenomenon or shared regional errors (i.e., shared within a CU), evidence for a regional autocorrelational component was also investigated. Evidence for a regional autocorrelational effect was investigated by fitting the following mixed effect model with different autocorrelational effects on the residual error:

$$Average\ Log\ Escapement = Brood + CU(R).$$

Model ranking results indicated support for a first order moving-average modeled (i.e., ARMA(0,1) or MA(1)) for the regional error (Table C4). Higher order autocorrelation effects were not tested due to convergence issues.

While evidence for autocorrelational effects were found at both the PU- and CU-level this does not imply these signatures were independent (a limitation of the testing used). Through trial and error it was determined that a first order moving-average effect (i.e., MA(1)) at the regional level (i.e., Equation 9) could reproduce much of the autocorrelational signatures observed at the PU-level (see Appendix D Validation Analyses). As such, this simpler form was employed.

BROODLINE WITHIN PU ESTIMATES

Consistency of broodline effects and potential associations between broodline effects were investigated though the use of a nested mixed effect model. Broodline effects were modeled as a nested random effect within the PU random effect:

$$Log\ Escapement = CU + PU(R) + Broodline(PU)(R).$$

Where CU is a fixed effect capturing systematic differences between CUs, $PU(R)$ is a random effect representing differences between PUs and $Broodline(PU)(R)$ is a nested random effect representing broodline differences within each PU. Fixed effect estimates were then used to compare the consistency of broodline effects across the sampled PUs (i.e., Figure 6b) as well as relationships between broodline effects within each PU.

Relationships between broodlines were investigated using a stepwise approach where the estimated broodline A effect was first described (Table C5) followed by broodline B (Table C6) and broodline C (Table C7). Model sets for B and C considered other broodlines as a potential descriptor, while the model set for broodline A did not. This was necessitated by the fact if differing broodlines are interrelated one broodline will need to be generated first, broodline A was arbitrarily chosen to fullfil this role. Both broodline B and C results (Table C6 and Table C7 respectively) showed strong support for broodline A as a descriptor, as such the top broodline A model was chosen. This model also had the same form which was desirable form a simplicity standpoint. Finally, the Broodline A model ranking results (Table C5) showed identical support for the Null (i.e., intercept only) and PU models, because PU was generally found to have support as a descriptor, the PU model was chosen for implementation in the data simulator. This had the additional benefit of allowing a further distinguisher between PUs which could be important for sampling schemes that take different approaches to sampling PUs. Finally, the Broodline B and C models had a CU effect that was not directly included in the simulator model (i.e., see Equation 8) because each CU was implemented independently in the simulator.

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Table C1. Longest consecutive escapement series for each broodline within each POPID/PU.

PU (POPID)	CU	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
1925	LFR									C	A		C	A	B	C	A	B	C	A
2436	LFR										A	B	C	A	B	C	A	B	C	A
44644	LFR	A			A															
46035	LFR						C			C	A		C	A	B	C	A	B	C	A
46079	LFR									C			C			C				
46968	LFR					B	C		B	C	A		C	A		C	A		C	A
46977	LFR					B	C		B	C	A			A			A			A
46992	LFR								B	C	A	B	C	A	B	C	A	B		
46996	LFR		B	C		B	C		B	C				A			A			A
47005	LFR		B	C		B	C		B	C	A		C	A		C	A		C	A
47022	LFR								B	C	A	B	C	A	B	C	A			
47044	LFR								B	C	A	B	C	A	B		A	B		
47058	LFR		B	C		B	C		B	C	A	B		A			A			A
47067	LFR								B	C	A	B	C	A	B	C	A	B		
47097	LFR					B	C		B	C	A		C	A		C	A		C	A
47555	LFR		B			B			B							C	A		C	A
47901	LFR	A	B	C	A	B	C	A	B	C	A									
47908	LFR						C	A	B	C	A	B	C	A	B	C				
47923	LFR							A		C	A	B	C	A	B	C	A			
47931	LFR		B	C		B	C		B	C			C	A		C	A		C	A
47946	LFR												C	A	B	C	A	B	C	A
47955	LFR					B			B					A		C	A		C	A
47961	LFR					B	C		B	C	A		C	A		C	A		C	A
47966	LFR	A	B	C	A	B	C	A	B		A	B		A						
47976	LFR					B	C		B	C	A		C	A						
47988	LFR	A	B	C	A	B	C		B	C			C							
47998	LFR		B	C		B	C		B	C	A			A			A			A
48010	LFR					B	C		B	C	A		C	A		C	A		C	A
48021	LFR					B	C		B	C	A		C	A		C	A		C	A
564	LFR								B	C	A	B	C	A	B	C	A	B	C	A
7472	LFR					B	C		B	C	A		C	A		C	A		C	A
46084	LILL									C			C			C				
46094	LILL									C			C			C				
46099	LILL								B	C	A	B	C	A		C	A		C	A
46103	LILL								B	C		B	C				A			A
46108	LILL								B	C	A	B	C	A			A			
46113	LILL								B		A	B		A			A			A
46123	LILL										A			A						
46153	LILL								B		A	B	C	A	B	C	A	B	C	A
69298	LILL												C			C				

Table C2. Model ranking results for comparing fixed effect models describing PU escapement.

Model	K	AICc	*Δ*AICc	AICc Weight	Cumulative Weight	Log Likelihood
CU:Broodline	8	1151.29	0	0.56	0.56	-567.43
CU:Broodline + Yr	9	1152.66	1.37	0.28	0.84	-567.06
CU:Broodline + CU:Yr	10	1154.14	2.85	0.13	0.97	-566.74
Broodline	8	1157.24	5.95	0.03	1	-570.4
CU*yr	6	1221.53	70.24	0	1	-604.64
Yr	4	1223.28	71.99	0	1	-607.58
Null (intercept only)	3	1228.96	77.67	0	1	-611.44
CU	4	1229.18	77.89	0	1	-610.53

Table C3. Model ranking results comparing the performance of different ARMA models on the residual error of the top ranked fixed effect models for PU escapement (Table C2).

Model	K	AICc	*Δ*AICc	AICc Weight	Cumulative Weight	Log Likelihood
ARMA(2,2)	10	1149.35	0	0.32	0.32	-564.34
ARMA(0,2)	8	1150.41	1.06	0.19	0.5	-566.99
ARMA(2,0)	8	1151.76	2.41	0.09	0.6	-567.67
ARMA(0,3)	9	1152.26	2.9	0.07	0.67	-566.86
ARMA(1,0)	7	1152.39	3.04	0.07	0.74	-569.03
ARMA(1,2)	9	1152.39	3.04	0.07	0.81	-566.93
ARMA(3,0)	9	1152.69	3.33	0.06	0.87	-567.07
ARMA(1,1)	8	1153.28	3.92	0.04	0.91	-568.42
ARMA(2,1)	9	1153.44	4.09	0.04	0.96	-567.45
ARMA(0,1)	7	1153.61	4.26	0.04	0.99	-569.64
Null	6	1156.97	7.61	0.01	1	-572.36

Note: The null model includes the same fixed and random effect model, but does not include any autocorrelational effects on the residual error.

Table C4. Model ranking results for different autoregressive moving average (ARMA) models used to describe autocorrelation in the average CU escapement between years.

Model	**K**	**AICc**	***Δ*AICc**	**AICc Weight**	**Cumulative Weight**	**Log Likelihood**
ARMA(0,1)	4	71.15	0	0.39	0.39	-30.78
ARMA(1,0)	4	72.89	1.74	0.17	0.56	-31.65
Null	3	73.56	2.41	0.12	0.68	-33.32
ARMA(1,1)	5	73.72	2.57	0.11	0.79	-30.61
ARMA(0,2)	5	73.75	2.6	0.11	0.9	-30.63
ARMA(2,0)	5	75.45	4.3	0.05	0.94	-31.48
ARMA(3,0)	6	76.18	5.03	0.03	0.97	-30.26
ARMA(2,1)	6	76.86	5.71	0.02	1	-30.61
ARMA(2,2)	7	80.25	9.1	0	1	-30.58
ARMA(1,2)	-	-	-	-	-	-

Note: Blank rows indicate models that failed to converge. The null model includes the same fixed and random effect model, but does not include any autocorrelational effects on the residual error.

Table C5. Model ranking results for models describing estimated broodline A within PU effects.

Model	**K**	**AICc**	***Δ*AICc**	**AICc Weight**	**Cumulative Weight**	**Log Likelihood**
Null	2	-3.29	0	0.37	0.37	3.83
PU	3	-3.17	0.11	0.35	0.73	4.96
CU	3	-0.91	2.38	0.11	0.84	3.83
CU+PU	4	-0.64	2.65	0.1	0.94	4.96
CU*PU	5	0.32	3.61	0.06	1	5.84

Table C6. Model ranking results for models describing estimated broodline B within PU effects.

Model	**K**	**AICc**	***Δ*AICc**	**AICc Weight**	**Cumulative Weight**	**Log Likelihood**
C + C:CU	4	-14.71	0	0.29	0.29	12.07
A + CU + A:CU:PU	6	-14.43	0.28	0.25	0.55	14.77
A*CU	5	-13.09	1.62	0.13	0.68	12.62
C*CU	5	-12.41	2.3	0.09	0.77	12.32
Null	2	-11.13	3.58	0.05	0.82	7.76
A only	3	-10.98	3.73	0.05	0.86	8.89
A:PU	3	-10.39	4.32	0.03	0.9	8.6
C only	3	-10.37	4.34	0.03	0.93	8.6
A + A:CU	4	-9.93	4.78	0.03	0.96	9.65
A + A:CU:PU	5	-9.67	5.04	0.02	0.98	10.91
C:PU	3	-8.22	6.49	0.01	0.99	7.52

Table C7. Model ranking results for models describing estimated broodline C within PU effects.

Model	**K**	**AICc**	***Δ*AICc**	**AICc Weight**	**Cumulative Weight**	**Log Likelihood**
A + CU + A:CU:PU	6	-11.75	0	0.78	0.78	13.49
A + A:CU:PU	5	-8.43	3.32	0.15	0.93	10.33
A + A:CU	4	-5.72	6.03	0.04	0.97	7.57
A only	3	-4.02	7.73	0.02	0.99	5.42
A*CU	5	-2.98	8.77	0.01	1	7.6
A:PU	3	1.87	13.62	0	1	2.48
B + B:CU:PU	5	2.35	14.09	0	1	4.94
B:PU	3	2.84	14.59	0	1	2
B + CU + B:CU:PU	6	3.21	14.96	0	1	6.01
B + C:CU	4	3.73	15.48	0	1	2.85
B only	3	4.58	16.33	0	1	1.12

APPENDIX D VALIDATION ANALYSES

Validations were conducted based on the longest consecutive series of escapement observations for each broodline within each PU (Table C1) to the behaviour of simulated data for the same PUs and years. Validations were done at the aggregate level (i.e., average escapement at the CU level) and at the PU level. A total of 1,000 simulated values were used to validate the data simulator. All analyses employed mixed effect models fit with the `nlme` package in the R computing environment (Pinheiro et al. 2017, R Core Team 2017). Model rankings were performed using the small-sample Akaike Information Criterion (AICc) on models fit using maximum likelihood estimation (Burnham and Anderson 2002; Mazerolle 2017, R Development Core Team 2017).

AGGREGATE VALIDATION

The year average CU escapement was fit with a mixed effect model of the following form:

$$Average\ Log\ Escapement = Broodline + CU(R)$$

where $Brood$ represents a fixed effect represent systematic differences between broodlines and $CU(R)$ is a random effect representing differences between CUs. The residual error was modeled as having an autoregressive moving-average (ARMA) signature equivalent to MA(1) (i.e., ARMA(0,1)). The ARMA component represents similarity between yearly average log escapement values within each CU. The same mixed effect model was then fit both the observed and simulated data where the same PUs and years were retained (Table D1). Overall, the simulated data produced estimates that were similar to estimates obtained from the observed data. Note that a reliable estimate of the CU random effect variability was not possible for the observed data.

Table D1. Validation results for simulator behaviour at the aggregate level (i.e., average CU escapement).

		Observed	**Simulation**	
Type	**Parameter**	**Estimate**	**Mean**	**SD**
Fixed	Brood A	6.23	6.12	0.27
	Brood B	6.85	6.51	0.27
	Brood C	6.36	6.41	0.26
Random Effect	CU SD	–	0.16	0.26
Residual Error	ARMA$(0,1)$: θ_1	0.54	0.47	0.24
	Residual SD	0.71	0.90	0.14

Note: Blank value indicates an unreliable estimate.

PU VALIDATION

The simulator behaviour at the PU-level was also compared to the observed data by fitting linear mixed models to the yearly log escapement values for each PU. The linear mixed models were of the following form:

$$Log\ Escapement = CU\!:\!Broodline + PU(R)$$

where $CU\!:\!Broodline$ is an fixed effect allowing each broodline effect within each CU to be estimated separately and $PU(R)$ is a random effect term representing systematic differences between PUs. The residual error was modeled as having an ARMA signature equivalent to MA(2) (i.e., ARMA(0,2)) and represents similarity between yearly log escapement values within each PU. While there was also support for an ARMA(2,2) model (see Appendix C Ancillary Analyses) this more complex model showed practical convergence issues that could skew validation results. Because the simpler MA(2) model also had strong support (i.e., ΔAICc < 2), and did not show the same convergence issues, it was used to validate the behaviour of the data simulator. The same mixed effect model was then fit both the observed and simulated data where the same PUs and years were retained (Table D2). Overall, the simulated data produced estimates that were similar to estimates obtained from the observed data. A notable exception was the second order lag term (θ_2), because a second order autocorrelation effect was not included in the simulation model the resulting in an estimate of zero, which differed from the observed data. Finally, the residual standard error in the simulator was designed to be slightly lower that the observed residual error variability to account for the fact the variation in the observed data already incorporates assessment method uncertainty which will be added back into the simulated data depending on the methods being assessed.

Table D2. Validation results for simulator behaviour at the PU level (i.e., average PU escapement).

Type	**Parameter**	**Observed Estimate**	**Simulation Mean**	**Simulation SD**
Fixed	LFR Brood A	4.74	4.94	0.33
	LFR Brood B	5.89	5.48	0.32
	LFR Brood C	5.20	5.20	0.32
	LILL Brood A	4.58	4.81	0.48
	LILL Brood B	6.29	5.66	0.49
	LILL Brood C	3.93	4.89	0.43
Random Effect	PU/POPID (SD)	1.35	1.40	0.18
Residual Error	ARMA(0,2): θ_1	0.21	0.17	0.13
	ARMA(0,2): θ_2	0.24	0.00	0.13
	Residual (SD)	1.10	1.00	0.10

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